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HBP Pilot Void Acceptance Projects in Region 2 in 1997

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Summaries and analyses of three Void Acceptance (VA) projects are reported and compared with previous VA and QA&QC projects. **Conclusions:** For two of three projects, the voids filled with asphalt (VFA) averaged 77% (design criteria was 65-75%) and percent air voids (AV) averaged 3.2% (design target was 4.0%). Because compacted bulk specific gravity field tests were higher than lab-mixed design values, for all processes, field AV and VMA averaged 0.4% below design values. VMA was easily met after field targets were adjusted. Precision of field AV tests and uniformity of contractor's production shows asphalt pavements cam be built with QL and incentive-disincentive type VA specifications. **Implementation:** Consider effects on VFA when making field changes in the job-mix formula. Be very careful about reducing the field AV and VMA targets below design. VMA tolerances should be tightened. Give more weight to AV and less to VMA in calculating composite pay factors. Make designs on plant-mixed asphalt mixtures if possible to eliminate field changes in AV and VMA. More training is is required for industry and CDOT on volumetric property testing and relationships. Increase the number of VA pilot projects.

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HBP PILOT VOID ACCEPTANCE PROJECTS IN REGION 2 IN 1997

BACKGROUND & STARTING THE VOID ACCEPTANCE PILOT PROGRAM

In the late 1980's, when the Colorado Department of Transportation (CDOT) was aggressively investigating ways to improve performance of hot bituminous pavement (HBP), they identified rutting as a major problem. Studies showed rutting was closely related to HBP volumetric properties. In 1990, Demonstration Project No 74, Field Management of Asphalt Mixes, by the Federal Highway Administration, was in progress. It focused on voids control. In 1991, D'Angelo and Ferragut (1) reported on the project. They showed the importance of asphalt mix volumetric control during construction.

Rutting performance of asphalt pavements in Colorado was reported(2) by Aschenbrener in 1992. Among other important findings, he emphasized the need for close voids control during construction.

CDOT announced, their intent in 1993 to adopt QC&QA void acceptance (VA) specifications for HBP by the end of the decade. To accomplish this, they constructed and evaluated a series of pilot projects. CDOT and industry have used the projects to become familiar with volumetric design, testing and construction. The program confirmed the feasibility of the VA premise and helped define testing and construction parameters. In 1996, CDOT began adoption of the Superpave(3) design procedure. This temporarily slowed VA implementation.

By the end of 1996, nine VA pilot projects had been completed. In May 1997, Brakey reported(4) on those projects. No new VA pilot projects were let to contract in 1997, but three were constructed. Two were carried over from 1996 and one was a QC&QA project changed to VA by change order. This report gives details of the 1997 projects and summarizes all 12. It is the final report on work done under the Phase 1 VA pilot program. Phase 2 VA pilot work will continue as described below.

PHASE 2 HBP VOID ACCEPTANCE PILOT PROGRAM

A series of VA projects is being let to contract in 1998 under a Phase 2 pilot specification (Exhibit 1). It combines the QPM 2 specification(5) with the volumetric design and testing experience gained from the Phase 1 program. CDOT plans on each of their Regions contracting two VA projects in 1998. More projects per Region will be done the following two years. The Phase 2 VA specification closely resembles the QPM 2 specification described below, except that VMA and AV elements have been added, and the gradation element dropped. "W" and "V" factors, and tolerance limits for VMA and AV are as specified in the Phase 1 program. In-place density and asphalt content (AC%) requirements are similar to QPM 2. One significant difference in Phase 2, from Phase 1, is that contractors must do QC testing for VMA and AV.

In addition, QC testing for gradation, Hveem stability and Lottman (resistance to moisture damage) are specified. None of these will be QC&QA pay elements. CDOT expects no problems in relation to contractor testing of density and asphalt content. Under QPM 1 and QPM 2, contractors made and reported thousands of these tests. However, at least two or three years will be required for the contractors and private labs to gear up for volumetric tests and become proficient at performing and interpreting them.

No target date has been set for the VA Phase 2 specification to replace the QPM 2 specification. It may never entirely replace it. CDOT expects to use the two specifications concurrently. Gradually, they will use the VA specification for more HBP work as the pilot program continues.

QC&QA PILOT PROGRAM (QPM 1) AND IMPLEMENTATION (QPM 2)

In 1992, CDOT started the QC&QA pilot program for HBP. The computer software designation for that specification is QPM 1; a copy of the specification is included in the 1993 report[6]. It requires field evaluation for materials pay factors (PF) to be done on three elements, in-place density (compaction), asphalt content and aggregate gradation. The contractor is required to make and report quality control (QC) tests for these elements (at a greater frequency than acceptance). Specifications include comprehensive QC testing schedules and requirements.

CDOT randomly samples and tests the above three elements for quality acceptance (QA). They evaluate results by standard statistical methods. Percent within tolerance, or quality level (QL), is established for each lot, or process. Statistical formulas, using QL and "n", determine the PF (incentive/disincentive (I/D) payments) for each process.

Under QPM 1, more than three million tons of HBP were produced during four construction seasons, 1992-1995. The QPM 1 phase was scheduled for completion in 1994, but several projects were held over and completed in 1995. Following collection and analysis of the 1994 data, a revised and updated QC&QA standard [5] special specification (QPM 2) was prepared and use began in 1995. About two million tons have been produced under QPM 2. To date there has been six reports on the two programs, one each year, 1993 through 1998 [(6) through (11)]. Six years of QC&QA construction has established its full feasibility. CDOT currently uses it for all HBP projects except experimental and pilot work.

The QPM 1 and 2 programs in 1992 through 1997 were independent of the VA pilot program. Phase 1 VA specifications are similar in format to QPM 1, but contractors have not been required to do quality control testing. A brief description of the VA specification follows below.

THE PHASE 1 VOID ACCEPTANCE PILOT SPECIFICATION

The Phase 1 VA specifications(4) did not require field acceptance of aggregate gradations. However, for each mix design approval, the source aggregates had to meet several aggregate parameters, including a master gradation range and nominal size. Based on acceptable mix design results, CDOT established a job mix gradation formula for the contractor's use in plant control. On any given mix design, precise gradations are related only subjectively to performance. Several aggregate characteristics affect mix volumetric properties, and consequently performance. However, under the VA end-result specification, it was not deemed appropriate to specify them for field acceptance.

Volumetric control of HBP mixtures requires making several laboratory tests on mixes and their components. Besides asphalt content, voids in the mineral aggregate (VMA) and air voids (AV) are calculated from results of complex specific gravity tests on aggregates and mixes. Contractors are learning to control aggregate characteristics, in addition to gradation, that affect voids properties. The I/D payment schedule helps motivate them. Pavements built under VA specifications are expected to perform better than those where volumetric properties are not controlled, with or without gradation as an acceptance element. CDOT is selectively evaluating certain VA pilot projects for performance. Data is not available at this time, but no performance problems have been reported.

The Phase 1 VA pilot specification(4) (used for the last six projects in 1996 and 1997) differed little from that used for the first six. Stability was included as an element on those first projects. The mixes were designed by Texas gyratory (TxG) laboratory compaction. Hveem stabilometer measured stability on TxG compacted specimens. On the last six projects, Superpave Level 1 Mix Design(3) was used. In Superpave (SP) laboratory compaction, the loose, hot asphalt mixture is placed in molds and subjected to gyrations for compaction. Air voids, at initial, design and endpoint gyrations, are estimated by automatic specimen height measurement. Test specimens compacted to endpoint gyrations are not satisfactory for stability testing. To test for stability, separate specimens compacted at design gyrations are required. Hveem stability testing is not included in the SP procedure. Until now, stability has not been included as a pay element on VA projects designed by SP.

SUMMARIZED DATA FROM 1997 VA PILOT PROJECTS

Table A1 summarizes field data from the three 1997 VA pilot projects. Data has been sorted by subaccount and process numbers. Following each element, process averages (weighted by tons) are shown. The abbreviated column headings are mostly self-explanatory. They identify the table components. There are two PF columns, first for VA and second for QPM 2. The QPM 2 data was not a component of the projects. It is shown for comparison. Phase 2 VA projects will use this method for PF calculations. Contractors' Code (CNT CDE) refers to codes used by CDOT for the various QC&QA contractors. The column for Aggregate Grading designation shows SF for all 1997 work. S is 3/4" nominal SP grading; F shows it is on the fine side of the maximum density line. The last two columns list the number and average result of the samples sent to the CDOT central laboratory for check testing.

At the end Table A1, composite QL and PF values for the combination of elements are shown. The composite values are the totals of the element values multiplied by their "W" factors. "W" is a relative weighting factor assigned to elements for the composite calculation. The I/D dollars are the total for the three projects. For comparison, similar information is shown for 1997 QPM 2 reported projects.

In Table A2, the data are sorted in this order: (1) by element, (2) by Asphalt PG grades, (3)by subaccount and (4) by process number. Below each element group is a weighted average line. All average values have been weighted by tons represented. A summary for the three projects, similar to that shown for Table A1, appears at the bottom of the second page. The absolute difference, of test results from targets, is shown for each element immediately below the arithmetic average value. Look at the Asphalt % element for the significance of the two values. The average arithmetic difference is -0.02, only slightly below the average target. The absolute difference, however, is 0.09, showing that without regard to sign, the average process was 0.09 from the target. The average QL of 81.16 relates more to absolute difference than arithmetic difference.

Although, "percent voids filled with asphalt" (VFA) is not included in the contracts as a pay element, a listing follows the A2 summary (last page). It is for information only. CDOT's SP design acceptance procedure includes criteria for VFA. For medium-to-heavy traffic, the acceptable range is 65-75. To calculate an experimental QL, we assigned a target of 70 and a tolerance of 7.0. CDOT does not specify VFA for field acceptance criteria as it is redundant. It is calculated as follows, VFA = [(VMA - AV)/VMA] x 100. ***If AC%, air voids and VMA are controlled properly around design targets, VFA criteria will be met.*** VFA has a linear relation to AV and VMA. Figure 1 shows the relationship where the VMA target is 14.0 (lowest **design**-target allowed for grading S) and the AV target is 4.0 (target for ***all designs***). The effect of varying or maintaining AC% is not shown. By using these targets (and the design AC%), if production is controlled to give a PF of +1.0, Figure 1 shows there is only a slight possibility of VFA being outside acceptable ranges.

When they do voids analyses, the Central Laboratory calculates and reports VFA. CDOT field personnel are not required to calculate and report it. To show field conformity on the projects, we calculated VFA's and listed them at the end of Table A2. The relationship of volumetric parameters on Walsenburg - South is shown in Figure 2. Here, VMA and AV had PF's of 1.05 and 1.03, although 50% of VFA values were above 75. Note that both PF's could have been above 1.0, even with an average VFA of 78. The effect on VFA should be considered carefully when making field JMF changes.

Discussion of Data Represented by the Figures

Table 1 (below) lists figures included with this report. The figures appear after Table A3 (at the end of the text). Beginning with Figure 3, frequency distribution histograms and accumulated frequency curves are shown for each element, including VFA. To draw the graphs, all test values but density were adjusted (normalized). In-place density has a common job mix target (94.0) for all processes; no adjustment was necessary. For the other elements, process values were shifted to a common target (about the overall average). For example, the 3-project average target for AC% (Table A-2) was 5.17 (5.2 was used). The target for the first process listed is 4.8. Therefore, 0.4 was added to each value in the process to normalize the data around the common target of 5.2. The target for the next process was 5.6 and 0.4 was subtracted from each value, and so on. Once all the values in each process had been adjusted, pooled statistical calculations were made, frequencies calculated and figures plotted. This was done for each element, including VFA.

Table 1

Description of Figures

Description	Fig. No.	Description	Fig. No.
Air Voids versus VFA, Typical for 14% VMA & 4.0% Voids Target	1	%AC, % Frequency, Normal Curve & Field Distribution	9
AV vs VFA, Walsenburg-South for 13.5% VMA & 3.5% Voids Target	2	% AC, Accumulated Frequency, Normal & Field Curves	10
VFA, % Frequency, Normal Curve & Field Distribution	3	VMA, % Frequency, Normal Curve & Field Distribution	11
VFA, Accumulated Frequency, Normal & Field Curves	4	VMA, Accumulated Frequency, Normal & Field Curves	12
VFA, % Frequency, Normal Curve & Field Distrib., Pueblo So. not included	5	Air Voids, % Frequency, Normal Curve & Field Distribution	13
VFA, Accumulated Freq. Normal & Field Curves, Pueblo So. Not included	6	Air Voids, Accumulated Frequency, Normal & Field Curves	14
Density, % Frequency, Normal Curve & Field Distribution	7	Air Voids, % Freq, Normal Curve & Field Distrib., Pueblo So. not included	15
Density, Accumulated Frequency, Normal & Field Curves	8	Air Voids, Accum. Freq. Normal & Field Curves, Pueblo So. not included	16

Interpreting the Plotted Data

In the histogram figures, if the bar tops are uniformly close to the normal curve, the distribution is normal. Similarly, if the accumulated frequency curves are close to the normal curves, the pooled values are on target and normally distributed. Where the frequency curves or histograms are shifted, left or right, the data is off the target. Lack of normal distribution suggests faulty procedures in production control, sampling or testing.

Figures 1 and 2 (AV vs. VFA), are discussed above. Figures 3 and 4 are for pooled VFA values. Note that the histogram in Figure 3 is mostly to the right of the target of 70. From the distribution curve in Figure 3, only 40% of the population is within the design parameter of 75 (60% within the experimental limit of 77). Figures 5 and 6 show VFA data (without the Pueblo-South project that was in compliance). These graphs for the other two projects show 70% of the values were above the design limit of 75, and 50% above the experimental limit of 77. This shows the design targets for VMA and AV should not be adjusted in the field without careful consideration of the effects on VFA.

The density graphs (Figures 7 and 8) show nonuniform distribution with about 80 percent of the values below the target value. Examination of Table A2 data shows the lack of uniformity probably was caused by pooling processes with very different SD's. The asphalt-content graphs (Figure 9 and 10) show the values to be near normally distributed and only slightly off the target. Graphs (Figures 11 and 12) drawn from VMA data show poor distribution, but only 0.2 off the target. Air voids graphs (Figures 13 and 16) have the most uniform shapes. This is encouraging; it shows the contractors had uniform production and the CDOT testers were precise.

DISCUSSION OF ELEMENT DATA

Target and Mean - Target

In Tables A1 and A2, T-M (target value minus the mean value), is shown for each process element. Because all density process differences are negative, the algebraic and absolute differences are the same, 0.83. The average density of 93.17 is lower than desirable, more than 0.3% below the QPM 2 average of 93.5 (Table 4, 6th annual QC&QA report[11]). AC% average was 0.01, very close to the target, while the absolute difference was 0.09. Combined with a larger than normal SD, this gave a lower QL than 1997 QPM 2 [11], 87.3 compared with 92.0. More discussion of AC% follows under Standard Deviation.

For VMA, most of the differences (T-M) are positive. The absolute difference of 0.23 is almost the same as the algebraic difference of 0.22. The average algebraic difference is small, and positive, showing it was easy to meet the field-adjusted targets.

As on previous VA projects, the air voids' targets were difficult to meet. Average T-M for the 1996 SP projects [4] was -0.88, in 1997 it was -0.22, apparently a significant improvement. This statistic may be misleading. For seven of the nine processes, the field targets were changed from the design value of 4.0 to 3.5. Apparently, this was because the contractors had difficulty meeting the specified 4.0 percent voids while meeting the Lottman requirements (resistance to moisture damage). If the targets for all processes had been left at 4.0, compliance may have been more difficult.

In 1996 [(4)] the SP weighted average air void percent was 3.22, in 1997 it was 3.39, but this included one project where the target of 4.0 was met exactly. For the other two projects, the 7-process average was 3.22, the same as in 1996. In 1996[(4)], the weighted average SD was 0.58 and in 1997 it was 0.54. Statistically the two sets of data are identical. Figure 16 shows 90 percent of the population is below the design target of 4.0 percent and 25 percent is below the lower design tolerance of 2.8. However, only 2.0 percent is below the critical lower limit of 2.0[(12)] for high traffic[1] as suggested by Aschenbrener.

Standard Deviations as Related to Tolerances and V Factors

To aid understanding of the relationship of SD to Tolerances and "V" factors, Table 2 shows data from various QPM and VA summaries. We have divided VA projects into the three following groups:

(1) Projects designed by TxG and built in 1993-1996, which we compare with the QPM 1 projects built in 1992-1995. The lot sizes and PF formulas are similar for the two programs, as are mix design procedures and participating contractors.
(2) Projects done in 1996 designed by SP.
(3) Projects done in 1997 designed by SP. We compared groups 2 and 3 with QPM 2 projects built mostly in 1996 and 1997. They were built by contractors participating concurrently in both programs.

Among the more useful statistics gathered in this series of reports, are process-average SD's. When the VA pilot program was initiated in 1993, process SD's for VMA and AV were estimated[(2)] for each from tests on six conventional HBP projects in 1992. The "V" factor of 0.6 for each element was based on these tests. "V" is approximately 1.2 historical SD's. It is used in VA specifications (and QPM) to evaluate single sample lots for PF. By formula, disincentive payments are calculated in relation to "V" and the distance outside tolerances. If the value is within the tolerances, the PF is 1.0.

Also, SD is used to establish tolerances for elements with double limits. Tolerance band widths for QLA specifications are typically four SD's in width. This gives a seller's risk of 5%. When the VA specification was written, tolerance limits and "V" factors for asphalt content and density (Table 2) were already in effect, based on historical data. Tolerances for both, VMA and AV were set at ±1.2 SD, for a band width of 2.4. Table 2 lists SD and specification band widths for the elements in the Pilot VA program and those shared by the QPM projects.

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[1] Higher traffic translates to a greater laboratory compactive effort on the "standard", meaning a higher degree of compaction will be required during construction, hence less likely to rut.

Plant control and testing techniques for asphalt content are essentially the same for VA projects as for QPM projects. Therefore, the QPM 2 average SD (representing 14 times as many tons) is a better indicator of actual field variability than is the VA average. "V" should be 1.2 times the historical SD. The current "V" (VA and QPM 2) of 0.2 for AC% is almost exactly 1.2 times the QPM 2 average of 0.16. The tolerance band width of 0.6 is about four times the average SD. For AC%, no changes are recommended in "V" or tolerances. AC% SD's for all three VA groups are larger than for QPM. One reason is that the contractors may have varied the asphalt on VA jobs to meet AV or density targets. This would have provided more incentive than keeping asphalt content on target. "W" factors are 0.1 for AC%, 0.3 for AV and 0.4 for density. Varying the element with the smallest "W" affects I/D the least.

Table 2
SD & Tolerance Table

Identification	AC%	Density	VMA	Air Voids
Current Tolerances & "V" Factors for VA Elements				
VA and QPM "V" Factors	**0.20**	**1.10**	**0.6**	**0.6**
VA and QPM Tolerance Widths	**0.6**	**4.0**	**2.4**	**2.4**
Historical & '92 Projects	0.18	1.05	0.51	0.62
6 TxG VA Projects	0.19	1.00	0.36	0.51
3 SP VA 96 Projects	0.17	0.87	0.49	0.58
3 SP VA 97 Projects	0.20	0.81	0.45	0.55
Voids Acceptance Projects Weighted Averages				
6 SP '96-'97 AV Projects (4)	**0.19**	**0.82**	**0.46**	**0.56**
All VA Projects, '93-'97	**0.19**	**0.93**	**0.41**	**0.55**
1991-95 QPM 1(9)	0.15	1.01	NA	NA
1995-97 QPM 2(11)	0.16	0.93	NA	NA

In-place density, construction and testing techniques on AV and QPM projects are similar. The weighted average process SD is 0.93 for each summary, all VA projects and all QPM 2 projects. To test for "V", multiply 0.93 by 1.2; it yields 1.12 (the current "V" is 1.10). "V" is correct. To test the tolerance band, multiply 0.93 by four; it equals 3.72. The current band width is 4.0. Tolerances for AC% and density have been in use by CDOT for at least eight years and experience shows they are satisfactory. No changes are recommended.

From Tables A1 and A2, it appears one contractor achieved good QL's (and incentive payments), though the average was lower than typical. On Walsenburg - South (three processes), the average in-place density was only 92.8% (about 1.0% below 1997 QPM 2). Nevertheless, with a lower than normal SD of 0.68 (0.93 is historical), the VA PF was 1.018. However, by the QPM 2 formula, the PF would have been 0.98 (2.0% disincentive). See Table A1, Project STA 0251-143, Density element. ***Note that with uniform compaction, (small SD), incentive was achieved even with the low average field density.***

From Table 2, above, the tolerance for AV is correct. Four times the average SD value of 0.55 equals 2.2, compared with the current band width of 2.4. No change is recommended. For "V", 1.2 times 0.55 equals 0.66, compared with the current value of 0.6. "V" should be increased to 0.7, but with several additional pilot projects scheduled for 1998 (some in progress), changes can wait until the end of construction season.

The average SD value for VMA for all VA projects is 0.41 (Table 2), but for the six Superpave projects in '96 and '97, the average is 0.46. Multiplying 0.46 by 1.2 equals 0.55, compared with the current value of 0.6. No change for "V" is recommended. To check the band width, 0.46 multiplied by four equals 1.84, compared with the current 2.4. When convenient, the tolerance band should be changed to 2.0, ($\pm$ 1.0) from the target. This will maintain the seller's risk at the recommended 5.0%.

Quality Levels and Pay Factors

Table A3 compares VA project data with QPM data. Attention is directed to QL's and PF's. A summary for the 1997 HBP "QC for pay" pilot projects done in 1997 [13] is on the bottom line. For convenience, some SD data from Table 2 is repeated in Table A3. Note the following:

(1) For 1997 VA density and AC%, the QL and PF are less than for QPM 2, showing lower compliance.

(2) VMA QL's for 1997 VA and "QC for pay" projects are higher than for other VA groups, but all QL's are high. This shows that complying with tolerances for this element is easy.

(3) The AV QL and PF are much higher than for 1996 SP VA and the QC for pay pilots. Normally, complying with this element is difficult. One reason for the high QL's may be field adjustments that lowered the targets on two projects.

VA pay factor formulas [4] for the Phase 1 projects are more liberal than for Phase 2 [Exhib. 1]. Phase 1 formulas are based on small lot sizes rather than complete processes as with Phase 2. To obtain PF, first QL is calculated by CP-71[14]. SD, distances of process mean from tolerance limits and number of test values ("n") are calculation variables. Phase 2 PF formulas are modeled after the WASHTO[15] table for PF. Sellers' risks are built into the table (and formulas) such that the probabilities of receiving a given incentive or disincentive are the same (when staying on a constant control target), whatever sample size.

By Phase 2 (and QPM 2), when "n" is 200, and QL = 92, PF equals 1.0. As "n" decreases, the required QL to achieve a PF of 1.0 also decreases. This is related to sellers' risk due to increased sampling error as "n"grows smaller. When "n" is three (minimum for statistical analysis), a QL of 70 provides a PF of 1.0. Pay incentive or disincentive is calculated from QL and "n" using QPM 2 formulas(5). In Tables A1 and A2, the QPM 2 PF column is provided for comparison with the specified VA pay factor. The QPM 2 procedure will be used for future VA projects. At the end of Table A1, the composite QL's and PF's are the average of the element PF's, weighted by "W" factors. By QPM 2 formulas, the composite PF is about 1.3 percent less than by VA formulas. This results from lower PF's for elements with larger process "n"s, particularly in-place density.

In Tables A1 and A2, the VA I/D column shows the actual payments, based on the VA procedure for PF. On the second page of Table A2, the summary at the bottom shows the total incentive was $201,468, compared with $49,016 if calculated by QPM 2 (and Phase 2). To obtain high incentive payments under Phase 2 VA, the contractors will need to apply greater efforts than were needed under Phase 1.

DIFFERENCES IN PERCENT AIR VOIDS FROM DESIGN VALUES

Data from the previous nine VA projects (4) show field AV's were about 0.5% less than design AV's on lab-mixed materials. This phenomenon is real and is of concern to contractors. They are well aware of it, but not fully in agreement as to the causes. The average field AV on the 1997 VA projects was 3.4, 0.4 below the average 3.8 for mix designs (Table A4 summary). We did a limited study using data from the three project files to see if causes for the field AV reductions were identifiable.

We have listed data sets in Table A4 composed of AC%, VMA and AV, along with matched specific gravities (SpG) for mix designs, JMF's, and field tests. Five designs are listed with SpG's reported by the central lab. On the lines below each design are the job mix formulas (JMF) changes made in the field. Immediately below each JMF change is the weighted average field data for AC% and voids properties. From these and the combined aggregate SpG's, the maximum (max) and compacted bulk (bulk) SpG's were calculated as shown. The changes in field percent AV (plus or minus from the designs), are listed in the last three columns.

To aid in understanding the study results, consider the following relationships:

(1) The difference between max and bulk, divided by max, times 100 equals AV%. Example: [(2.422-2.325)/2.422] x 100 = 4.0.

(2) When the ***field max is higher*** than design max, the effect is to ***increase the field AV%***. Field max is more likely to be higher than lower, but only slightly. One cause may be higher internal absorbed moisture or asphalt in the field.

(3) When the ***field bulk is higher*** than design bulk, the effect is to ***decrease the field AV%***. Field bulk is more likely to be higher than lower, sometimes by a substantial amount. Two causes could be more mineral filler (dust) and higher effective aggregate SpG (from absorption).

(4) When the ***differences*** between field max and field bulk ***are less*** than between design max and design bulk, the effect is to ***decrease* the field AV%** from design. This is the most likely occurrence.

(5) A "rule-of-thumb" for evaluating the above relationships is that the difference in compared SpG's (to three decimals) multiplied by 4.0 x 10 (or 40) equals approximately the AV%. (See 1, above, for exact procedure for calculating AV%).

Test the "rule-of-thumb" by going to Table A4 and selecting the third line down under "North of Trinidad". Field max minus design max = 0.005; multiplying this by 40 = 0.2; (MxSpGr column). Design bulk minus field bulk = - 0.034; multiplying this by 40 = -1.4; (BlkSpGr column). Field change in AV% is the total of the two columns, -1.2 (Total column). We evaluated each of the nine processes and tabulated the results. Considerable variation exists in the amounts of field change, but the changes were consistent for each mix design and course. Changes in AV% are closely related to mix constituent characteristics (aggregate and asphalt).

The second page of Table A4 has a summary showing averages (weighted by number of acceptance tests) of field changes for each mix design. For the Trinidad job, with ***very absorptive aggregate***, the total AV% change was about the same for bottom and top courses (- 0.8 and -0.9). Contributions by each, max and bulk were different by 0.8% (bottom course compared with top course). The averages of actual field SpG's for both courses were about the same (Table Summary).

However, design SpG's for the two mixtures were quite different. All things were the same for the two courses, except asphalt type and percent. Asphalt for the bottom was unmodified, optimum was 5.6%. A polymer modified asphalt was used for the top; optimum was 5.2%. Asphalt content was about the same for both courses in the field. For the two designs, difference in design max SpG's was probably related to asphalt content. The difference in design bulk SpG's probably was related to asphalt characteristics (unmodified versus modified). However, the design differences had a canceling effect, resulting in the same net change in field AV% for each course.

Field SpG's for Pueblo had no changes in AV% from mix design (related to max) for either top or bottom course. The aggregate had ***low absorptivity***. For the bottom course, field bulk changed slightly, resulting in +0.1 AV%. The change was +0.4 AV% for the top, the same amount as for the Trinidad top, but in the ***opposite*** direction.

Only top course was placed under VA specifications on the Walsenburg project. Here the aggregate had ***medium absorptivity.*** AV% (related to max) changed uniformly, about +0.2 for all processes. A uniform change (related to bulk) of about -0.8 occurred for all processes. The net change in AV% is similar to the top course on the Trinidad project, -0.6 compared with -0.8. However, max contributions were opposite for the two top courses, +0.2 compared with -0.4. Also, the bulk contribution to AV reduction at Walsenburg was double that at Trinidad, -0.8 compared with -0.4.

Based on this small study, field AV% changes from design do not show ***clear relationships*** to any of the variables studied. However, on these projects trends are evident as follows:

(1) High-absorptive aggregates cause more reduction in field AV than do low-absorptive aggregates. Ranking of the three projects showed the most absorptive aggregate (at Trinidad) had the most change and the least absorptive aggregate (Pueblo) had the least change.

(2) Field AV% changes from max effects are usually smaller than from bulk effects. For the nine-process average, field-max minus design-max is +0.002. The SD of differences is 0.008. ***Field max tests changed AV by +0.1% average.*** Two thirds of the time, the AV change was less than +0.3%. Changes in field AC% likely contribute significantly to these changes.

(3) Field AV% are usually affected more by bulk changes than by the max changes. This was true for all processes except the two top course processes at Trinidad. For the nine-process average, design-bulk minus field-bulk is -0.013. The SD of differences is 0.015. The change due to bulk effects is six times greater than change due to max effects. ***Field bulk tests changed AV by -0.5% average.*** Two thirds of the time, the AV change due to bulk was less than -0.60. Several things, variable from project to project, likely contributed to these changes.

In this limited study, we were unable to quantify the causes of the field SpG changes from designs on lab-mixed materials. The possibilities are many. A few likely causes follow:

(1) Changes from design in field aggregate characteristic (a likely cause is increased mineral dust).

(2) Changes in asphalt percent and characteristics.

(3) Asphalt-absorption changes by the aggregate (due to mixing and storage time and temperature differences).

(4) Moisture-absorption changes by the aggregate (due to heating and drying differences).

(5) Sampling and testing variables (random differences) or bias (consistent differences).

The trends and causes of changes discussed above are not necessarily applicable to designs made on plant-mixed materials.

DIFFERENCES IN VMA FROM DESIGN VALUES

Field VMA changes from design values are related to increases or decreases in the bulk specific gravity of laboratory compacted specimens in the same manner as AV changes are related. That is, if AV is reduced 0.5% due to an increased field bulk SpG value, VMA will decrease by 0.5% also. Max SpG values do not directly affect VMA, as they do AV. If field max SpG is the same as design max (and asphalt content is the same), VMA and AV change will be in concert as field bulk SpG varies from design.

In the above discussion on field changes in SpG, we have concentrated on AV, the most critical element related to pavement rut resistance. ***However, a key to overcoming field reduction in AV most likely will be the contractors' ability to increase (or maintain) VMA through control of aggregate characteristics, including micro texture, gradation and mineral dust.***

OVERALL PHASE 1 VOIDS ACCEPTANCE CONCLUSIONS

Conclusion from this study, and previous VA and QPM projects are as follows:

(1) VFA design criteria had poor compliance on two of the three 1997 projects. Average was 76.7 with 70% of the population above the upper design limit of 75. Using the experimental control limit of 77, the QL was only 53.3.

(2) Average air-voids percent was 3.2 on two of the three projects, much lower than the desired target of 4.0. However, good QL's were achieved with field targets set at 3.5. Only 2.0 percent of the population was below the critical limit of 2.0. Considering the VFA and AV parameters, the projects may be edging toward critical rut resistance limits.

(3) VMA criteria were easily met, once field targets were established. The result was an average QL of 98.9. This agrees favorably with values obtained by CDOT on previous VA projects and on the QC for Pay Pilot projects of 1997. The "W" factor and tolerance limits probably need adjusted.

(4) "V" factors for Density, AC% and VMA are correct; "V" for AV is lower than it should be.

(5) Tolerance limits are correct for density, AC% and AV; tolerances for VMA are larger than they should be.

(6) For Phase 2, more effort will be required of contractors to achieve the same incentive payments received on Phase 1 projects. Control testing is required on all four pay elements. Under Phase 2, the contractor cannot continue production if either, the QC 5-test QL or the QA moving 5-test QL, is less than 65 (PF of 0.93). However, for only a 5% risk of production stoppage due to random causes, it requires a 5-test average QL of ***87*** (PF of 1.03). ***Contractors should focus on maintaining a QL that provides small risks of work stoppage.***

(7) Histograms and curves show that experienced CDOT testers did a good job on the AV tests, the curves are smooth and the SD's are reasonable. The contractors had uniform AV production control. With training and experience, other CDOT labs, contractors and private labs can reproduce these results.

(8) Field maximum theoretical SpG's were higher than design values. This caused an increase in field AV%, an average of 0.1%. Asphalt content reduction from design is one likely cause. Increased moisture and asphalt absorption (into the aggregate) may have contributed to higher max values.

(9) Field compacted bulk SpG's were higher than lab-mixed design values. This caused an average change in field AV% and VMA of -0.5%. Increases in mineral dust, in absorption of asphalt and moisture into the aggregate, and asphalt characteristic changes were the most likely causes for the changes. Bulk changes were about five to six times as much as max changes, and were responsible for most of the field AV% decrease and all of the VMA decrease.

RECOMMENDATIONS

(1) Pay more attention to the VFA parameters. It is not recommended that VFA be a pay element. Nevertheless, calculate and consider it routinely when setting up or changing job mix formulas in the field. VFA may be adversely affected by shifting field VMA and AV targets away from ideal design targets.

(2) Decrease the "W" factor for VMA to 0.1. The historical VA/SP average SD is about 0.45. Decrease the tolerance to $\pm$ 1.0. For a seller's risk of 5%, it should be two historical SD's. Leave "V" at 0.6. It should be 1.2 times the historical average SD for a seller's risk of 5%.

(3) Increase the "W" factor for AV to 0.4. The historical VA/SP average SD is 0.56. Leave the tolerance at $\pm$ 1.2. For a seller's risk of 5%, it should be two historical SD's. Increase "V" to 0.7. It should be 1.2 times the historical average SD for a seller's risk of 5%.

(4) Thoroughly train CDOT and industry personnel involved with volumetric testing and production so they understand the relationships portrayed in Table A4 and related discussions. Much more than being proficient at testing is needed. Required knowledge includes ability to quantify the effects on AV% and VMA due to variances in the several specific gravity tests and knowing the most likely causes of the variances.

(5) One way to avoid the problem of reduced AV% and VMA in the field (from lab-mixed mixture designs) is to make lab designs from plant mixed materials. Where this is not practical, contractors should plan necessary time and facilities to allow field adjustment at start-up. This requires education, experience and intuition. Always consider the secondary effects of field design (JMF) changes on VFA, field density and the Lottman values.

(6) Allow adjustment in lab-mixed designs (higher AV, VMA and lower VFA) to account for anticipated field changes. This could reduce trial and error associated with field adjustments. Procedures, specific to contractor and historical source data, would need to be developed.

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Table A1

CDOT REGION 2 HOT BITUMINOUS PAVEMENT VOIDS ACCEPTANCE QC/QA

DETAILS AND SUMMARY BY PROJECT AND MIX DESIGN FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD	SUBAC NUMBR	PRC No	ELE-MENT	BID $ / TON	TONS 1000	TEST "n"	PROCESS DATA CALC TARG	MEAN	T-M	SD	QUAL LEVL	VA PF	QPM2 PF	VA I/D $	CNT CDE	AGG GRAD	CENTRAL LAB CHECKS "n"	MEAN
	PG-																		
							IR(CX) 025-1(122)												
I 25, North of Trinidad	64-28	91025	2	Dns%	$28.50	23.50	47	94.0	93.35	-0.65	0.76	96.4	1.043	1.050	$11,520	C4	SF	NA	NA
I 25, North of Trinidad	64-28	91025	3	Dns%	$28.50	40.50	81	94.0	93.26	-0.74	0.63	97.7	1.046	1.023	$21,294	C4	SF	NA	NA
I 25, North of Trinidad	76-28	91025	4	Dns%	$30.25	16.00	32	94.0	93.86	-0.14	1.27	88.8	1.023	1.003	$4,402	C4	SF	NA	NA
I 25, North of Trinidad	76-28	91025	5	Dns%	$30.25	43.50	87	94.0	93.56	-0.44	0.72	98.5	1.048	1.060	$25,049	C4	SF	NA	NA
PROJECT TOTALS & AVERAGES FOR DENSITY					$29.34	123.50	247	94.0	93.46	-0.54	0.77	96.6	1.043	1.039	$62,265	C4	SF	NA	NA
I 25, North of Trinidad	64-28	91025	2	AC%	$28.50	23.50	23	5.6	5.42	-0.18	0.22	69.1	0.870	0.867	($34,760)	C4	SF	4	5.38
I 25, North of Trinidad	64-28	91025	3	AC%	$28.50	40.50	41	5.3	5.37	0.07	0.19	63.1	0.999	0.792	($499)	C4	SF	4	5.18
I 25, North of Trinidad	76-28	91025	4	AC%	$30.25	16.00	16	5.3	5.29	-0.01	0.26	74.8	0.931	0.890	($13,265)	C4	SF	3	5.40
I 25, North of Trinidad	76-28	91025	5	AC%	$30.25	43.50	44	5.3	5.36	0.06	0.19	86.7	1.001	0.982	$553	C4	SF	4	5.38
PROJECT TOTALS & AVERAGES FOR AC%					$29.34	123.50	124	5.4	5.36	0.01	0.21	74.0	0.966	0.886	($47,971)	C4	SF	15	5.31
I 25, North of Trinidad	64-28	91025	2	VMA	$28.50	23.50	23	14.0	13.99	-0.01	0.37	100.0	1.042	1.050	$11,356	C4	SF	4	14.59
I 25, North of Trinidad	64-28	91025	3	VMA	$28.50	40.50	41	14.0	14.08	0.08	0.43	99.5	1.045	1.055	$20,703	C4	SF	4	14.51
I 25, North of Trinidad	76-28	91025	4	VMA	$30.25	16.00	16	14.0	14.17	0.17	0.52	98.1	1.042	1.050	$8,122	C4	SF	3	15.00
I 25, North of Trinidad	76-28	91025	5	VMA	$30.25	43.50	44	14.0	14.00	0.00	0.37	99.9	1.047	1.056	$24,507	C4	SF	4	14.70
PROJECT TOTALS & AVERAGES FOR VMA					$29.34	123.50	124	14.00	14.05	0.05	0.41	99.6	1.045	1.054	$64,687	C4	SF	15	14.66
I 25, North of Trinidad	64-28	91025	2	Voids	$28.50	23.50	23	3.5	2.80	-0.70	0.58	80.5	0.976	0.955	($6,507)	C4	SF	4	4.13
I 25, North of Trinidad	64-28	91025	3	Voids	$28.50	40.50	41	3.5	3.27	-0.23	0.64	92.4	1.030	1.024	$13,994	C4	SF	4	4.55
I 25, North of Trinidad	76-28	91025	4	Voids	$30.25	16.00	16	3.5	3.42	-0.08	0.69	93.0	1.026	1.037	$5,067	C4	SF	3	4.60
I 25, North of Trinidad	76-28	91025	5	Voids	$30.25	43.50	44	3.5	3.18	-0.33	0.49	96.5	1.042	1.051	$22,301	C4	SF	4	4.13
PROJECT TOTALS & AVERAGES FOR AIR VOIDS					$29.34	123.50	124	3.50	3.17	-0.33	0.58	91.7	1.024	1.022	$34,855	C4	SF	15	4.33
PROJECT TOTALS & AVERAGES FOR ITEM					**$29.34**	**123.50**	**NA**	**NA**	**NA**	**NA**	**NA**	**93.5**	**1.030**	**1.021**	**$113,835**	**C4**	**SP**	**NA**	**NA**
							IM 0251-141												
So of Pueblo - North	64-28	11371	1	Dns%	$36.80	16.93	34	94.0	93.81	-0.19	1.06	94.1	1.038	1.037	$9,489	W2	SF	NA	NA
So of Pueblo - North	70-34	11371	2	Dns%	$37.50	43.50	87	94.0	92.92	-1.08	1.11	79.2	0.960	0.907	($25,976)	W2	SF	NA	NA
PROJECT TOTALS & AVERAGES FOR DENSITY					$37.30	60.43	121	94.0	93.17	-0.83	1.10	83.4	0.982	0.944	($16,487)	W2	SF	NA	NA
So of Pueblo - North	64-28	11371	1	AC%	$36.80	16.93	17	4.8	4.68	-0.12	0.26	71.6	0.886	0.903	($28,476)	W2	SF	3	5.03
So of Pueblo - North	70-34	11371	2	AC%	$37.50	43.50	44	4.8	4.61	-0.19	0.24	76.4	0.914	0.904	($56,069)	W2	SF	6	5.02
PROJECT TOTALS & AVERAGES FOR AC%					$37.30	60.43	61	4.8	4.63	-0.17	0.24	75.1	0.906	0.904	($84,546)	W2	SF	9	5.02

Table A1

CDOT REGION 2 HOT BITUMINOUS PAVEMENT VOIDS ACCEPTANCE QC/QA

DETAILS AND SUMMARY BY PROJECT AND MIX DESIGN FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD PG-	SUBAC NUMBR	PRC No	ELE-MENT	BID $ / TON	TONS 1000	TEST "n"	PROCESS DATA CALC TARG	MEAN	T-M	SD	QUAL LEVL	VA PF	QPM2 PF	VA I/D $	CNT CDE	AGG GRAD	CENTRAL LAB CHECKS "n"	MEAN
So of Pueblo - North	64-28	11371	1	VMA	$36.80	16.93	17	13.0	13.79	0.79	0.57	76.1	0.942	0.935	($14,510)	W2	SF	3	14.07
So of Pueblo - North	70-34	11371	2	VMA	$37.50	43.50	44	13.0	13.61	0.61	0.65	81.9	0.993	0.946	($4,894)	W2	SF	6	14.30
PROJECT TOTALS & AVERAGES FOR VMA					$37.30	60.43	61	13.0	13.66	0.66	0.63	80.3	0.978	0.943	($19,404)	W2	SF	9	14.23
So of Pueblo - North	64-28	11371	1	Voids	$36.80	16.93	17	4.0	4.05	0.05	0.84	85.6	1.017	0.996	$4,278	W2	SF	3	3.57
So of Pueblo - North	70-34	11371	2	Voids	$37.50	43.50	44	4.0	3.98	-0.02	0.67	93.0	1.011	1.027	$6,923	W2	SF	6	4.10
PROJECT TOTALS & AVERAGES FOR AIR VOIDS					$37.30	60.43	61	4.0	4.00	-0.00	0.72	90.9	1.012	1.018	$11,201	W2	SF	9	3.95
PROJECT TOTALS & AVERAGES FOR ITEM					$37.30	60.43	NA	NA	NA	NA	NA	87.5	1.000	0.996	($109,235)	W2	SF	NA	NA
STA 0251 - 143																			
Walsenburg - South	70-34	11783	A	Dns%	$31.56	24.00	48	94.0	92.87	-1.13	0.81	85.9	1.013	0.974	$3,793	H1	SF	NA	NA
Walsenburg - South	70-34	11783	B	Dns%	$31.56	30.00	60	94.0	92.85	-1.15	0.67	89.9	1.026	1.000	$9,987	H1	SF	NA	NA
Walsenburg - South	70-34	11783	C	Dns%	$31.56	35.87	72	94.0	92.67	-1.33	0.61	86.4	1.014	0.968	$6,340	H1	SF	NA	NA
PROJECT TOTALS & AVERAGES FOR DENSITY					$31.56	89.87	180	94.0	92.78	-1.22	0.68	87.4	1.018	0.980	$20,120	H1	SF	NA	NA
Walsenburg - South	70-34	11783	A	AC%	$31.56	24.00	24	5.1	5.10	0.00	0.16	94.1	1.038	1.043	$11,528	H1	SF	3	5.20
Walsenburg - South	70-34	11783	B	AC%	$31.56	30.00	30	5.2	5.23	0.03	0.14	97.1	1.045	1.050	$17,020	H1	SF	3	5.30
Walsenburg - South	70-34	11783	C	AC%	$31.56	35.87	36	5.2	5.26	0.06	0.15	94.0	1.038	1.039	$17,108	H1	SF	4	5.48
PROJECT TOTALS & AVERAGES FOR AC%					$31.56	89.87	90	5.2	5.21	0.04	0.15	95.0	1.040	1.044	$45,656	H1	SF	10	5.34
Walsenburg - South	70-34	11783	A	VMA	$31.56	24.00	24	13.3	13.25	-0.05	0.46	99.5	1.049	1.045	$14,925	H1	SF	3	13.90
Walsenburg - South	70-34	11783	B	VMA	$31.56	30.00	30	13.3	13.40	0.10	0.30	100.0	1.050	1.050	$18,936	H1	SF	3	13.27
Walsenburg - South	70-34	11783	C	VMA	$31.56	35.87	36	13.3	13.69	0.39	0.42	97.5	1.046	1.050	$20,699	H1	SF	4	13.78
PROJECT TOTALS & AVERAGES FOR VMA					$31.56	89.87	90	13.3	13.47	0.17	0.39	98.9	1.048	1.049	$54,560	H1	SF	10	13.64
Walsenburg - South	70-34	11783	A	Voids	$31.56	24.00	24	3.5	3.12	-0.38	0.60	91.6	1.031	1.032	$9,498	H1	SF	3	4.20
Walsenburg - South	70-34	11783	B	Voids	$31.56	30.00	30	3.5	3.12	-0.38	0.38	98.7	1.048	1.050	$18,095	H1	SF	3	3.13
Walsenburg - South	70-34	11783	C	Voids	$31.56	35.87	36	3.5	3.54	0.04	0.50	98.7	1.048	1.050	$21,664	H1	SF	4	3.50
PROJECT TOTALS & AVERAGES FOR AIR VOIDS					$31.56	89.87	90	3.5	3.29	-0.21	0.49	96.8	1.043	1.045	$49,257	H1	SF	10	3.56
PROJECT TOTALS & AVERAGES FOR ITEM					$31.56	89.87	NA	NA	NA	NA	NA	93.3	1.034	1.020	$169,593	H1	SF	NA	NA
Item Composite of 1997 Void Acceptance Projects												**91.35**	**1.021**	**1.008**	**$201,468**		$49,016	If by QPM 2	
Item Comp of 1997 QC/QA Projects					**$31.26**	**378.9**						**90.90**		**1.011**	**$102,530**				

Table A2

CDOT REGION 2 HOT BITUMINOUS PAVEMENT VOIDS ACCEPTANCE QC/QA
DETAILS AND SUMMARY BY ELEMENT & COURSE FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD PG-	SUBAC NUMBR	PRC No	ELE-MEN	BID $ / TON	TONS 1000	TEST "n"	PROCESS DATA CALC TARG	MEAN	T-M	SD	QUAL LEVL	VA PF	QPM2 PF	VA I/D $	CNT CDE	AGG GRAD	CENTRAL LAB CHECKS "n"	MEAN
So of Pueblo - North	64-28	11371	1	Dns%	$36.80	16.93	34	94.0	93.81	-0.19	1.06	94.1	1.038	1.037	$9,025	W2	SF	NA	NA
I 25, North of Trinidad	64-28	91025	2	Dns%	$28.50	23.50	47	94.0	93.35	-0.65	0.76	96.4	1.043	1.050	$14,147	C4	SF	NA	NA
I 25, North of Trinidad	64-28	91025	3	Dns%	$28.50	40.50	81	94.0	93.26	-0.74	0.63	97.7	1.046	1.023	$26,150	C4	SF	NA	NA
Weighted Averages and Totals, Bottom Courses					**$30.24**	**80.93**	**162**	**94.0**	**93.40**	**-0.60**	**0.76**	**96.6**	**1.044**	**1.034**	**$49,322**				
So of Pueblo - North	70-34	11371	2	Dns%	$37.50	43.50	87	94.0	92.92	-1.08	1.11	79.2	0.960	0.907	($24,244)	W2	SF	NA	NA
Walsenburg - South	70-34	11783	A	Dns%	$31.56	24.00	48	94.0	92.87	-1.13	0.81	85.9	1.013	0.974	$3,793	H1	SF	NA	NA
Walsenburg - South	70-34	11783	B	Dns%	$31.56	30.00	60	94.0	92.85	-1.15	0.67	89.9	1.026	1.000	$9,987	H1	SF	NA	NA
Walsenburg - South	70-34	11783	C	Dns%	$31.56	35.87	72	94.0	92.67	-1.33	0.61	86.4	1.014	0.968	$6,340	H1	SF	NA	NA
I 25, North of Trinidad	76-28	91025	4	Dns%	$30.25	16.00	32	94.0	93.86	-0.14	1.27	88.8	1.023	1.003	$5,094	C4	SF	NA	NA
I 25, North of Trinidad	76-28	91025	5	Dns%	$30.25	43.50	87	94.0	93.56	-0.44	0.72	98.5	1.048	1.060	$28,982	C4	SF	NA	NA
Weighted Averages and Totals, Top Courses					**$32.50**	**192.87**	**386**	**94.0**	**93.08**	**-0.92**	**0.84**	**88.2**	**1.012**	**0.984**	**$29,952**				
Weighted Averages and Totals For Density Processes					**$31.83**	**273.8**	**548**	**94.00**	**93.17**	**-0.83**	**0.81**	**90.66**	**1.021**	**0.998**	**$79,273**				
										0.83	**= Aver Absolute Diff of Process Averages**								
So of Pueblo - North	64-28	11371	1	AC%	$36.80	16.93	17	4.8	4.68	-0.12	0.26	71.6	0.886	0.903	($27,083)	W2	SF	3	5.03
I 25, North of Trinidad	64-28	91025	2	AC%	$28.50	23.50	23	5.6	5.42	-0.18	0.22	69.1	0.870	0.867	($42,688)	C4	SF	4	5.38
I 25, North of Trinidad	64-28	91025	3	AC%	$28.50	40.50	41	5.3	5.37	0.07	0.19	63.1	0.999	0.792	($612)	C4	SF	4	5.18
Weighted Averages and Totals, Bottom Courses					**$30.24**	**80.93**	**81**	**5.3**	**5.24**	**-0.05**	**0.21**	**66.6**	**0.938**	**0.837**	**($70,384)**			**11**	**5.20**
So of Pueblo - North	70-34	11371	2	AC%	$37.50	43.50	44	4.8	4.61	-0.19	0.24	76.4	0.914	0.904	($52,331)	W2	SF	6	5.02
Walsenburg - South	70-34	11783	A	AC%	$31.56	24.00	24	5.1	5.10	0.00	0.16	94.1	1.038	1.043	$11,528	H1	SF	3	5.20
Walsenburg - South	70-34	11783	B	AC%	$31.56	30.00	30	5.2	5.23	0.03	0.14	97.1	1.045	1.050	$17,020	H1	SF	3	5.30
Walsenburg - South	70-34	11783	C	AC%	$31.56	35.87	36	5.2	5.26	0.06	0.15	94.0	1.038	1.039	$17,108	H1	SF	4	5.48
I 25, North of Trinidad	76-28	91025	4	AC%	$30.25	16.00	16	5.3	5.29	-0.01	0.26	74.8	0.931	0.890	($15,348)	C4	SF	3	5.40
I 25, North of Trinidad	76-28	91025	5	AC%	$30.25	43.50	44	5.3	5.36	0.06	0.19	86.7	1.001	0.982	$639	C4	SF	4	5.38
Weighted Averages and Totals, Top Courses					**$32.50**	**192.87**	**194**	**5.1**	**5.11**	**-0.01**	**0.19**	**87.3**	**0.994**	**0.986**	**($21,384)**			**23**	**5.28**
Weighted Averages and Totals For Asphalt % Processes					**$31.83**	**273.8**	**275**	**5.17**	**5.15**	**-0.02**	**0.20**	**81.16**	**0.977**	**0.942**	**($91,768)**			**46**	**5.26**
										0.09	**= Aver Absolute Diff of Process Averages**								

Table A2

CDOT REGION 2 HOT BITUMINOUS PAVEMENT VOIDS ACCEPTANCE QC/QA
DETAILS AND SUMMARY BY ELEMENT & COURSE FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD PG-	SUBAC NUMBR	PRC No	ELE-MEN	BID $ / TON	TONS 1000	TEST "n"	PROCESS DATA CALC TARG	MEAN	T-M	SD	QUAL LEVL	VA PF	QPM2 PF	VA I/D $	CNT CDE	AGG GRAD	CENTRAL LAB CHECKS "n"	MEAN
So of Pueblo - North	64-28	11371	1	VMA	$36.80	16.93	17	13.0	13.79	0.79	0.57	76.1	0.942	0.935	($13,800)	W2	SF	3	14.07
I 25, North of Trinidad	64-28	91025	2	VMA	$28.50	23.50	23	14.0	13.99	-0.01	0.37	100.0	1.042	1.050	$13,946	C4	SF	4	14.59
I 25, North of Trinidad	64-28	91025	3	VMA	$28.50	40.50	41	14.0	14.08	0.08	0.43	99.5	1.045	1.055	$25,424	C4	SF	4	14.51
Weighted Averages and Totals, Bottom Courses					**$30.24**	**80.93**	**81**	**13.8**	**13.99**	**0.20**	**0.44**	**94.8**	**1.023**	**1.028**	**$25,571**			**11**	**14.44**
So of Pueblo - North	70-34	11371	2	VMA	$37.50	43.50	44	13.0	13.61	0.61	0.65	81.9	0.993	0.946	($4,567)	W2	SF	6	14.30
Walsenburg - South	70-34	11783	A	VMA	$31.56	24.00	24	13.3	13.25	-0.05	0.46	99.5	1.049	1.045	$14,925	H1	SF	3	13.90
Walsenburg - South	70-34	11783	B	VMA	$31.56	30.00	30	13.3	13.40	0.10	0.30	100.0	1.050	1.050	$18,936	H1	SF	3	13.27
Walsenburg - South	70-34	11783	C	VMA	$31.56	35.87	36	13.3	13.69	0.39	0.42	97.5	1.046	1.050	$20,699	H1	SF	4	13.78
I 25, North of Trinidad	76-28	91025	4	VMA	$30.25	16.00	16	14.0	14.17	0.17	0.52	98.1	1.042	1.050	$9,397	C4	SF	3	15.00
I 25, North of Trinidad	76-28	91025	5	VMA	$30.25	43.50	44	14.0	14.00	0.00	0.37	99.9	1.047	1.056	$28,355	C4	SF	4	14.70
Weighted Averages and Totals, Top Courses					**$32.50**	**192.87**	**194**	**13.4**	**13.68**	**0.23**	**0.45**	**95.2**	**1.035**	**1.027**	**$87,744**			**23**	**14.14**
Weighted Averages and Totals For VMA Processes					**$31.83**	**273.8**	**275**	**13.55**	**13.77**	**0.22**	**0.45**	**95.09**	**1.031**	**1.028**	**$113,315**			**46**	**14.23**
										0.23	**= Aver Absolute Diff of Process Averages**								
So of Pueblo - North	64-28	11371	1	Voids	$36.80	16.93	17	4.0	4.05	0.05	0.84	85.6	1.017	0.996	$4,069	W2	SF	3	3.57
I 25, North of Trinidad	64-28	91025	2	Voids	$28.50	23.50	23	3.5	2.80	-0.70	0.58	80.5	0.976	0.955	($7,991)	C4	SF	4	4.13
I 25, North of Trinidad	64-28	91025	3	Voids	$28.50	40.50	41	3.5	3.27	-0.23	0.64	92.4	1.030	1.024	$17,186	C4	SF	4	4.55
Weighted Averages and Totals, Bottom Courses					**$30.24**	**80.93**	**81**	**3.6**	**3.30**	**-0.31**	**0.66**	**87.5**	**1.012**	**0.998**	**$13,264**			**11**	**4.22**
So of Pueblo - North	70-34	11371	2	Voids	$37.50	43.50	44	4.0	3.98	-0.02	0.67	93.0	1.011	1.027	$6,461	W2	SF	6	4.10
Walsenburg - South	70-34	11783	A	Voids	$31.56	24.00	24	3.5	3.12	-0.38	0.60	91.6	1.031	1.032	$9,498	H1	SF	3	4.20
Walsenburg - South	70-34	11783	B	Voids	$31.56	30.00	30	3.5	3.12	-0.38	0.38	98.7	1.048	1.050	$18,095	H1,	SF	3	3.13
Walsenburg - South	70-34	11783	C	Voids	$31.56	35.87	36	3.5	3.54	0.04	0.50	98.7	1.048	1.050	$21,664	H1	SF	4	3.50
I 25, North of Trinidad	76-28	91025	4	Voids	$30.25	16.00	16	3.5	3.42	-0.08	0.69	93.0	1.026	1.037	$5,862	C4	SF	3	4.60
I 25, North of Trinidad	76-28	91025	5	Voids	$30.25	43.50	44	3.5	3.18	-0.33	0.49	96.5	1.042	1.051	$25,803	C4	SF	4	4.13
Weighted Averages and Totals, Top Courses					**$32.50**	**192.87**	**194**	**3.6**	**3.43**	**-0.18**	**0.55**	**95.5**	**1.034**	**1.042**	**$87,384**			**23**	**3.90**
Weighted Averages and Totals For Air Voids Processes					**$31.83**	**273.8**	**275**	**3.61**	**3.39**	**-0.22**	**0.58**	**93.17**	**1.028**	**1.029**	**$100,648**			**34**	**3.99**
										0.24	**= Aver Absolute Diff of Process Averages**								
Item Composite of 1997 Void Acceptance Projects (PG 64-28 AC) Bottom Courses												90.50	1.019	1.002	$17,772				
Item Composite of 1997 Void Acceptance Projects (PG 70-34 & 76-28 AC) Top Courses												91.71	1.021	1.010	$183,695				
Item Composite of 1997 Void Acceptance Projects (all elements & gradings)												**91.35**	**1.021**	**1.008**	**$201,468**	**$49,016 If by QPM 2**			
Item Comp of 1997 QC/QA Projects					**$31.26**	**378.9**						**90.90**		**1.011**	**$102,530**				

Table A2

CDOT REGION 2 HOT BITUMINOUS PAVEMENT VOIDS ACCEPTANCE QC/QA

DETAILS AND SUMMARY BY ELEMENT & COURSE FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD PG-	SUBAC NUMBR	PRC No	ELE-MEN	BID $ / TON	TONS 1000	TEST "n"	PROCESS DATA CALC TARG	MEAN	T-M	SD	QUAL LEVL	VA PF	QPM2 PF	VA I/D $	CNT CDE	AGG GRAD	CENTRAL LAB CHECKS "n"	MEAN
Experimental for this report. No Specifications have been established for Voids Filled with Asphalt. The limits used for QL calculations are + or - 7.0, For PF, "W" used is 0.1																			
So of Pueblo - North	64-28	11371	1	VFA	$36.80	16.93	17	70.0	70.80	0.80	5.26	81.7	0.986	0.972	($872)	W2	SF	3	72.67
I 25, North of Trinidad	64-28	91025	2	VFA	$28.50	23.50	23	70.0	80.10	10.10	3.71	80.5	0.771	0.484	($15,337)	C4	SF	4	71.66
I 25, North of Trinidad	64-28	91025	3	VFA	$28.50	40.50	41	70.0	76.90	6.90	4.04	51.0	0.879	0.679	($13,966)	C4	SF	4	68.83
Weighted Averages and Totals, Bottom Courses					**$30.24**	**80.93**	**81**	**70.0**	**76.55**	**6.55**	**4.20**	**66.0**	**0.870**	**0.684**	**($30,176)**			11	70.454
So of Pueblo - North	70-34	11371	2	VFA	$37.50	43.50	44	70.0	70.80	0.80	4.01	91.7	1.021	1.018	$3,426	W2	SF	6	71.50
Walsenburg - South	70-34	11783	A	VFA	$31.56	24.00	24	70.0	76.50	6.50	3.79	55.2	0.893	0.749	($8,105)	H1	SF	3	77.67
Walsenburg - South	70-34	11783	B	VFA	$31.56	30.00	30	70.0	76.79	6.79	2.41	53.4	0.887	0.717	($10,699)	H1	SF	3	76.33
Walsenburg - South	70-34	11783	C	VFA	$31.56	35.87	36	70.0	74.19	4.19	3.02	82.4	0.988	0.954	($1,359)	H1	SF	4	74.75
I 25, North of Trinidad	76-28	91025	4	VFA	$30.25	16.00	16	70.0	75.90	5.90	4.42	59.6	0.909	0.809	($4,404)	C4	SF	3	69.56
I 25, North of Trinidad	76-28	91025	5	VFA	$30.25	43.50	44	70.0	74.19	4.19	3.02	82.4	0.988	0.949	($1,579)	C4	SF	4	72.14
Weighted Averages and Totals, Top Courses					**$32.50**	**192.87**	**194**	**70.0**	**74.26**	**4.26**	**3.36**	**74.7**	**0.961**	**0.893**	**($22,720)**			23	73.61
Weighted Averages and Totals For Air Voids Processes					**$45.78**	**273.8**	**275**	**70.00**	**74.94**	**4.94**	**3.61**	**72.12**	**0.934**	**0.831**	**($45,440)**			**46**	**72.67**
										4.94	**= Aver Absolute Diff of Process Averages**								
															($128,066)	If by QPM 2			

Table A3
Density, Asphalt Content, VMA and AV Test Data
Void Acceptance Compared to QPM 1 & 2 and QC for Pay Projects

	"n" or Number of tests				Standard Deviation				Quality Level				QPM 1 PF or VA PF				QPM 2 PF			
Group Identification	Dn	AC	VMA	AV	Dn	AC	VMA	AV	Dn	AC	VMA	AV	Dn	AC	VMA	AV	Dn	AC	VMA	AV
VA, Texas Gyr. Design Constructed in 1993-96	615	316	316	316	1.00	0.19	0.36	0.51	84.1	86.3	93.4	92.9	0.978	1.000	1.023	1.024	0.966	0.997	1.022	1.024
1991-95, QPM 1	5729	3092			1.01	0.15			88.1	90.4			1.017	1.030			0.992	1.017		
VA, Superpave, 1996	171	86	86	86	0.87	0.17	0.49	0.58	77.7	79.6	91.2	82.6	0.892	0.956	1.002	0.978	0.907	0.944	1.013	0.960
VA, Superpave, 1997	548	275	275	275	0.81	0.20	0.45	0.55	90.7	81.2	95.1	93.2	1.012	0.994	1.031	1.027	0.984	0.977	1.028	1.029
1995-97, QPM 2	2785	1579			0.93	0.16			92.3	90.1			NA	NA			1.017	1.009		
QC for Pay, 1997	117	116	90	90	0.61	0.15	0.43	0.84	95.5	93.4	94.8	76.3			1.017	1.000	1.034	1.028	1.024	0.907

Table A4
Summary of Mix Designs and Field Data
1997 Pilot Void Acceptance Superpave Projects

Identity	AC %	VMA %	Air Vds %	Comb Agg Sp Gr	Theo Max Sp Gr	Comp Bulk Sp Gr	Field Accept, Contrib In Void% Change From Design		
							MxSpGr	BlkSpGr	Total
STA 0251-143 Walsenburg - South Top Course, PG 70-34 AC, 109 Gyrations, Design #86272, -3/4" S (fine), H_2O Abs = 1.2%, Abras. Loss = 28%									
Design	5.10	14.0	3.80	2.598	2.445	2.352			
Field, JMF #A	5.10	13.3	3.5		2.445	2.359	0.0	-0.3	-0.3
Avg 24 Accept	5.10	13.3	3.12		2.450	2.373	0.2	-0.8	-0.6
Field, JMF #B	5.2	13.3	3.5		2.443	2.357	-0.1	-0.2	-0.3
Avg 30 Accept	5.23	13.4	3.12		2.450	2.374	0.2	-0.9	-0.7
Field, JMF #C	5.20	13.3	3.50		2.454	2.368	0.3	-0.6	-0.3
Avg 36 Accept	5.26	13.7	3.54		2.454	2.367.	0.3	-0.6	-0.3
SUMMARY OF THREE PROJECTS & FIVE MIX DESIGNS									
Trinidad Bottom Design	5.60	15.5	4.0	2.594	2.422	2.325			
Field Wt. Avg	5.38	14.0	3.1	2.594	2.432	2.356	0.4	-1.3	-0.9
.Trinidad Top Design	5.20	14.5	4.0	2.594	2.445	2.347			
Field Wt. Avg	5.34	14.1	3.2	2.594	2.435	2.355	-0.4	-0.4	-0.8
Pueblo Bottom Design	4.60	13.8	4.0	2.615	2.466	2.368			
Field Wt. Avg.	4.68	13.8	4.1	2.615	2.465	2.365	0.0	0.1	0.1
Pueblo Top Design	4.60	13.2	3.5	2.615	2.466	2.380			
Field Wt. Avg.	4.61	13.6	4.0	2.615	2.467	2.369	0.0	0.4	0.4
Walsenburg Top Design	5.10	14.0	3.8	2.598	2.445	2.352			
Field Wt. Avg.	5.21	13.5	3.3	2.598	2.451	2.371	0.2	-0.8	-0.6
ALL DESIGNS WT. AVG.	**5.12**	**14.3**	**3.8**	**2.602**	**2.445**	**2.350**			
ALL FIELD WT. AVG.	**5.15**	**13.8**	**3.4**	**2.602**	**2.447**	**2.363**	**0.1**	**-0.5**	**-0.4**

Table notes: The compacted bulk specific gravities shown for the Field JMF's were calculated from the maximum specific gravities and AV targets shown on the Form 43's (JMF change). The field acceptance maximum and bulk specific gravities were calculated from AC%, AV and VMA data reported by the field.

Table A4
Summary of Mix Designs and Field Data
1997 Pilot Void Acceptance Superpave Projects

Identity	AC %	VMA %	Air Vds %	Comb Agg Sp Gr	Theo Max Sp Gr	Comp Bulk Sp Gr	Field Accept, Contrib In Void% Change From Design		
							MxSpGr	BlkSpGr	Total
IR(CX) 025-1(122) I 25, North of Trinidad Bottom Course, PG 64-28 AC, 109 Gyrations, Design #86272, -3/4" S (fine), H_2O Abs = 1.7%, Abras. Loss = 22%									
Design	5.60	15.5	4.0	2.594	2.422	2.325			
Field, JMF #1	5.60	14.0	3.50		2.422	2.337	0.0	-0.5	-0.5
Avg 23 Accept	5.42	14.0	2.80		2.427	2.359	0.2	-1.4	-1.2
Field, JMF #2	5.30	14.0	3.5		2.433	2.348	0.4	-0.9	-0.5
Avg 41 Accept	5.37	14.1	3.27		2.435	2.355	0.5	-1.2	-0.7
Top Course, PG 76-28 AC, 109 Gyrations, Design #86272, -3/4" S (fine), H_2O Abs = 1.7%, Abras. Loss = 22%									
Design	5.20	14.5	4.00	2.594	2.445	2.347			
Field, JMF #3	5.30	14.0	3.50		2.427	2.342	-0.7	0.2	-0.5
Avg 16 Accept	5.29	14.2	3.42		2.434	2.350	-0.5	-0.1	-0.6
Field, JMF #4	5.30	14.0	3.50		2.438	2.353	-0.3	-0.2	-0.5
Avg 44 Accept	5.36	14.0	3.18		2.435	2.357	-0.4	-0.4	-0.8
IM 0251-141 South of Pueblo - North Bottom Course, PG 64-28 AC, 109 Gyrations, Design #93301, -3/4" S (fine), H_2O Abs = 1.0%, Abras. Loss = 26%									
Design	4.60	13.8	4.00	2.615	2.466	2.368			
Field, JMF #1	4.80	13.0	4.00		2.458	2.360	-0.3	0.3	0.0
Avg 17 Accept	4.68	13.8	4.05		2.465	2.365	0.0	0.1	0.1
Top Course, PG 70-34 AC, 109 Gyrations, Design #93301, -3/4" S (fine), H_2O Abs = 1.0%, Abras. Loss = 26%									
Design	4.60	13.2	3.50	2.615	2.466	2.380			
Field, JMF #2	4.80	13.0	4.00		2.466	2.367	0.0	0.5	0.5
Avg 44 Accept	4.61	13.6	3.98		2.467	2.369	0.0	0.4	0.4

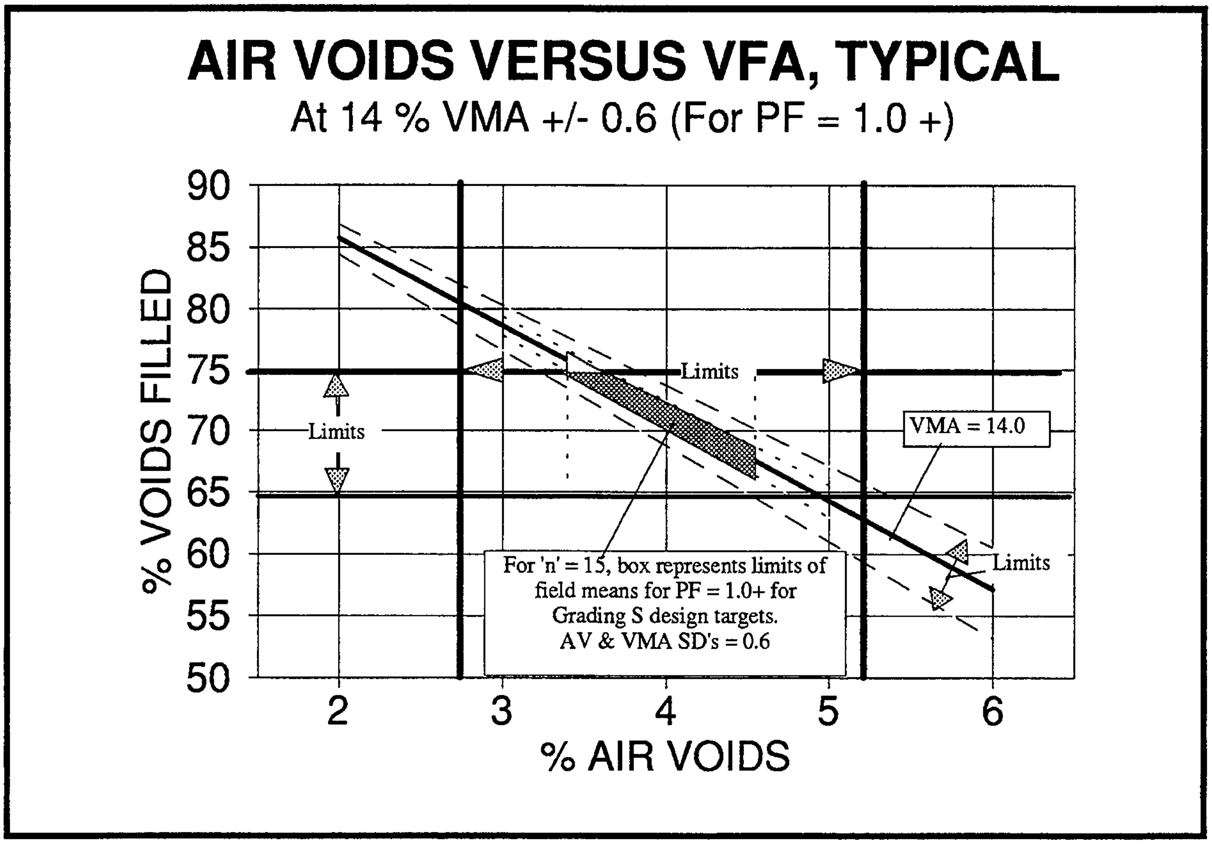

Figure 1

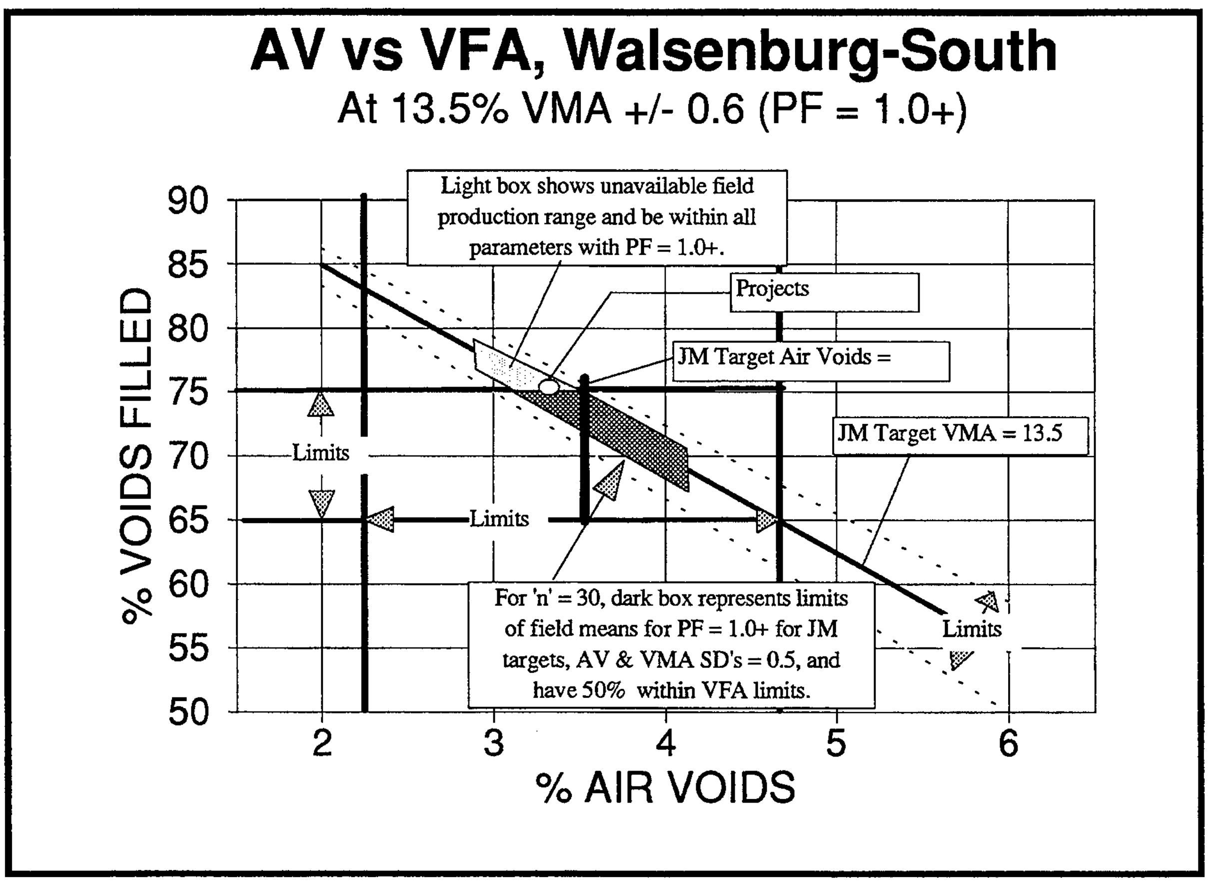

Figure 2

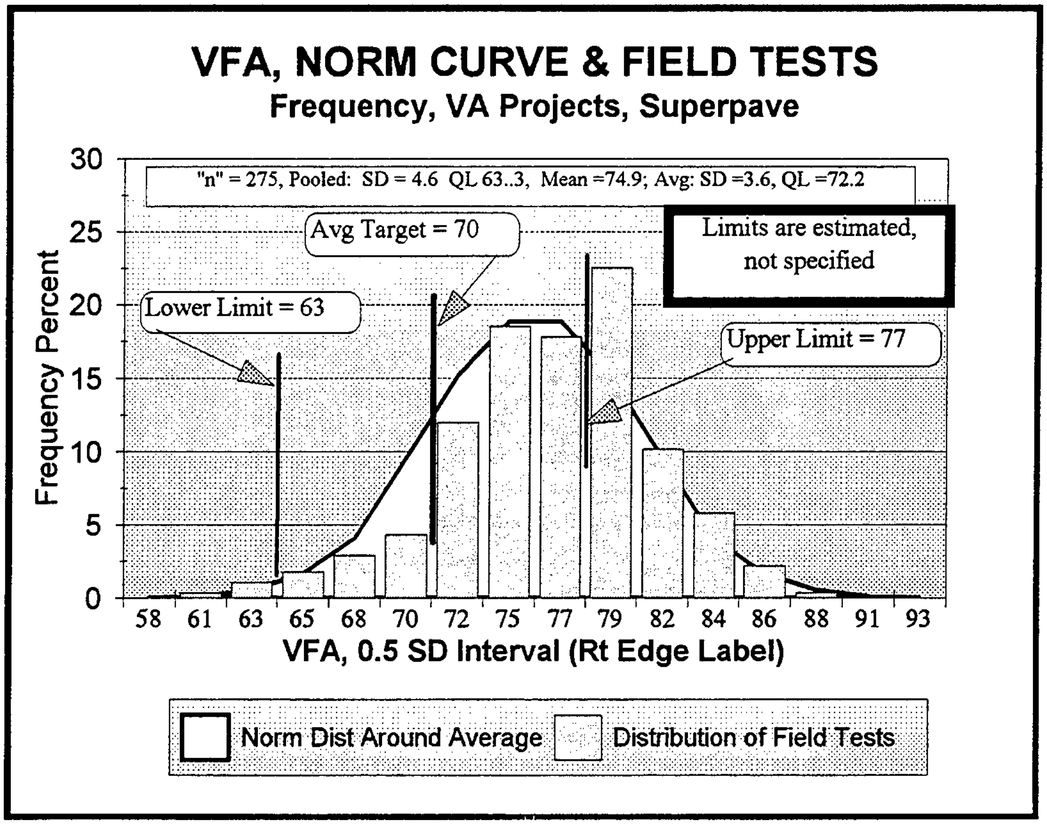

Figure 3

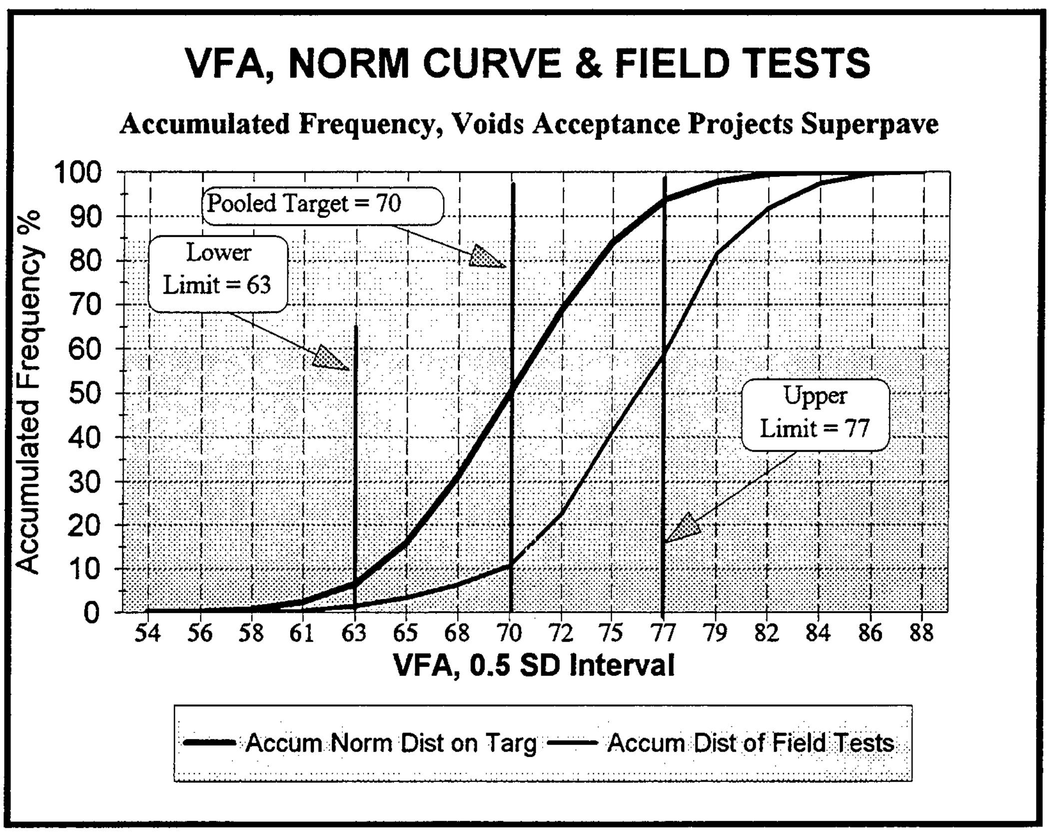

Figure 4

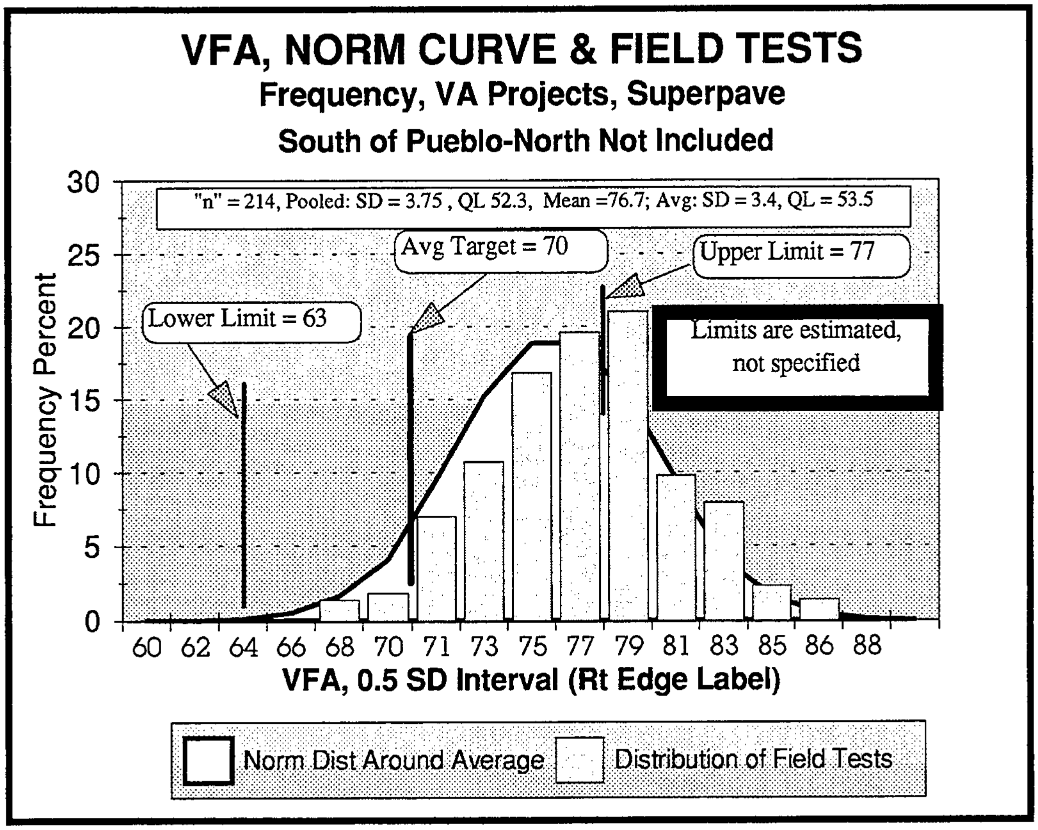

Figure 5

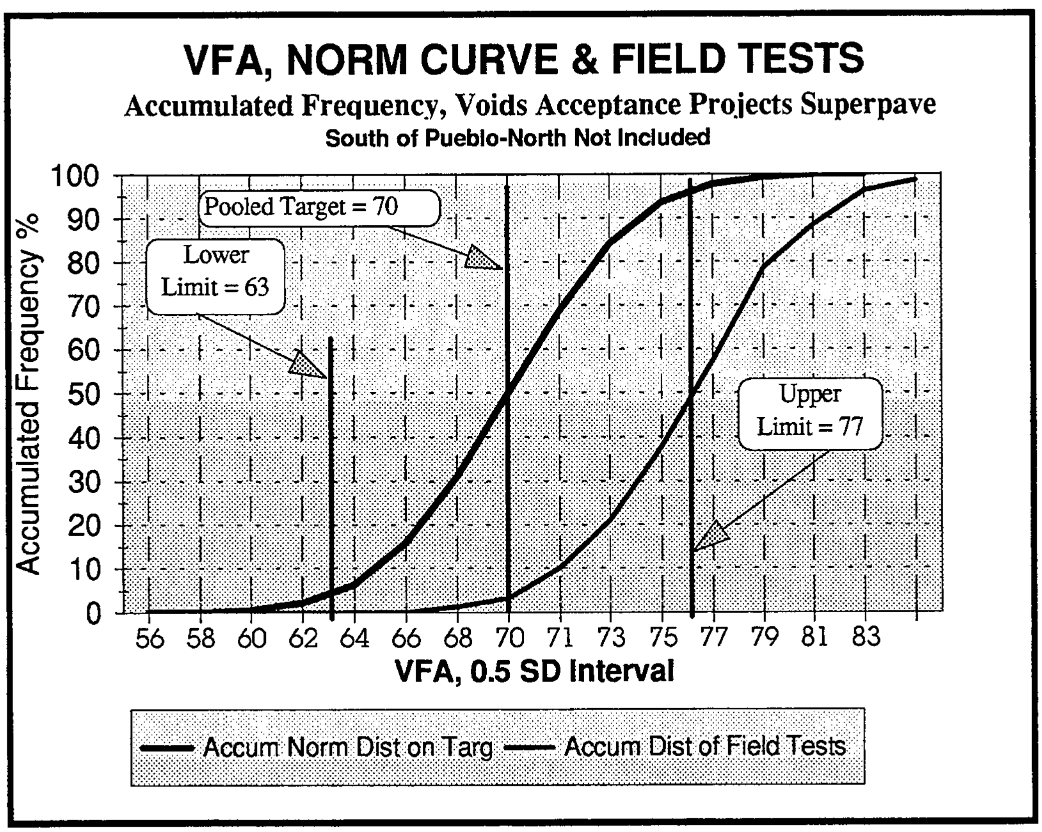

Figure 6

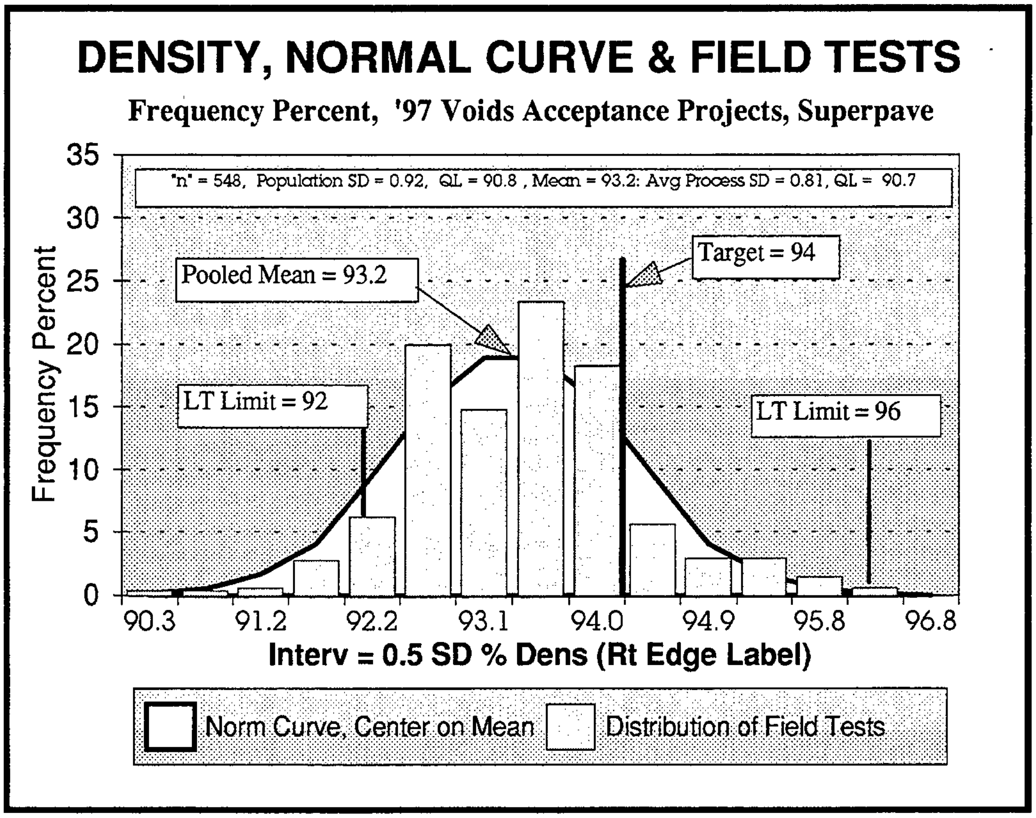

Figure 7

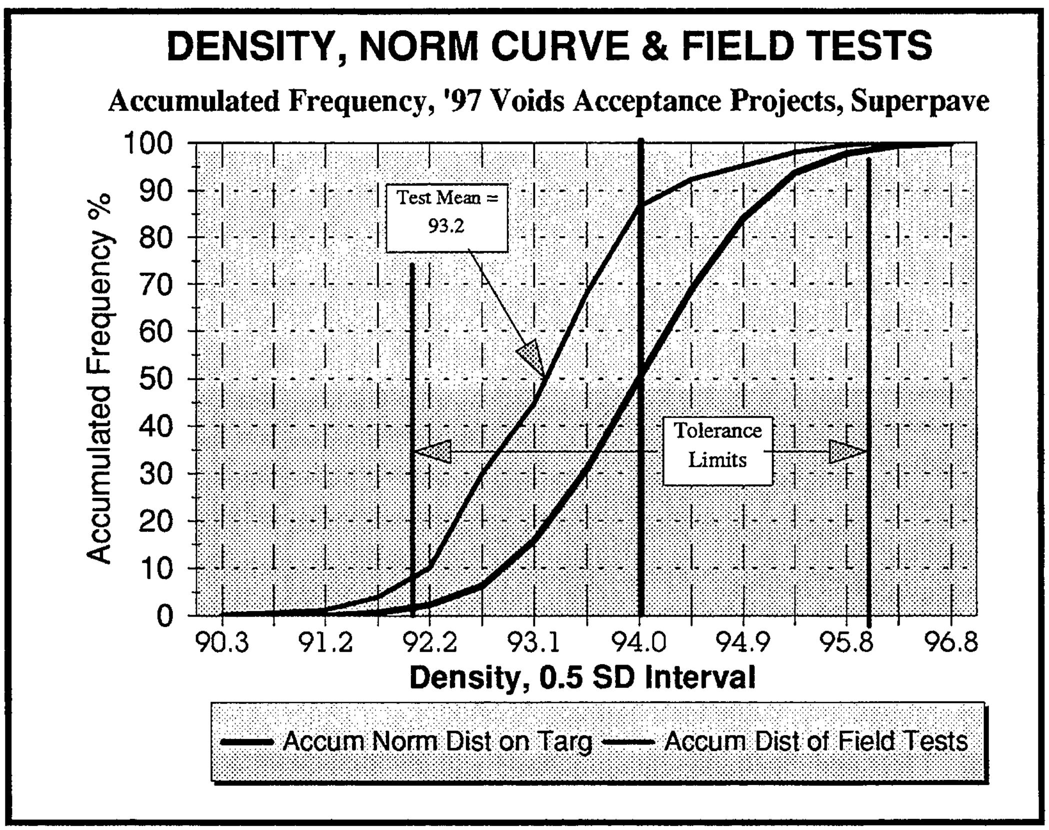

Figure 8

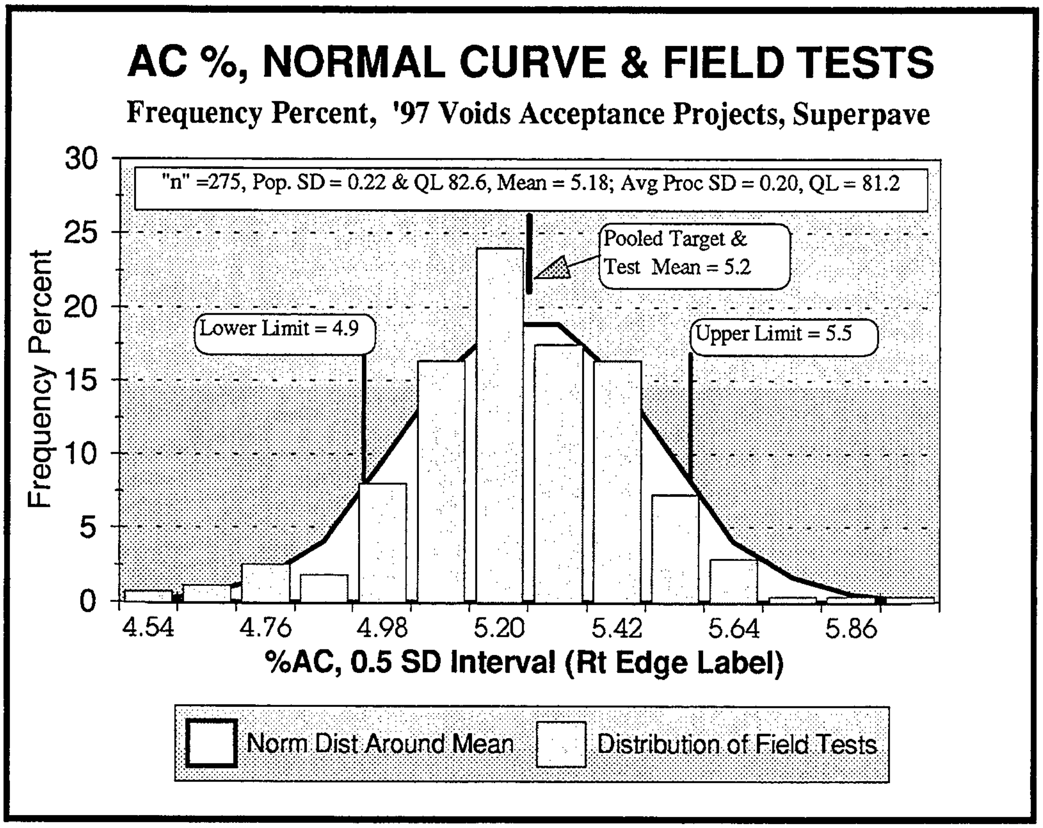

Figure 9

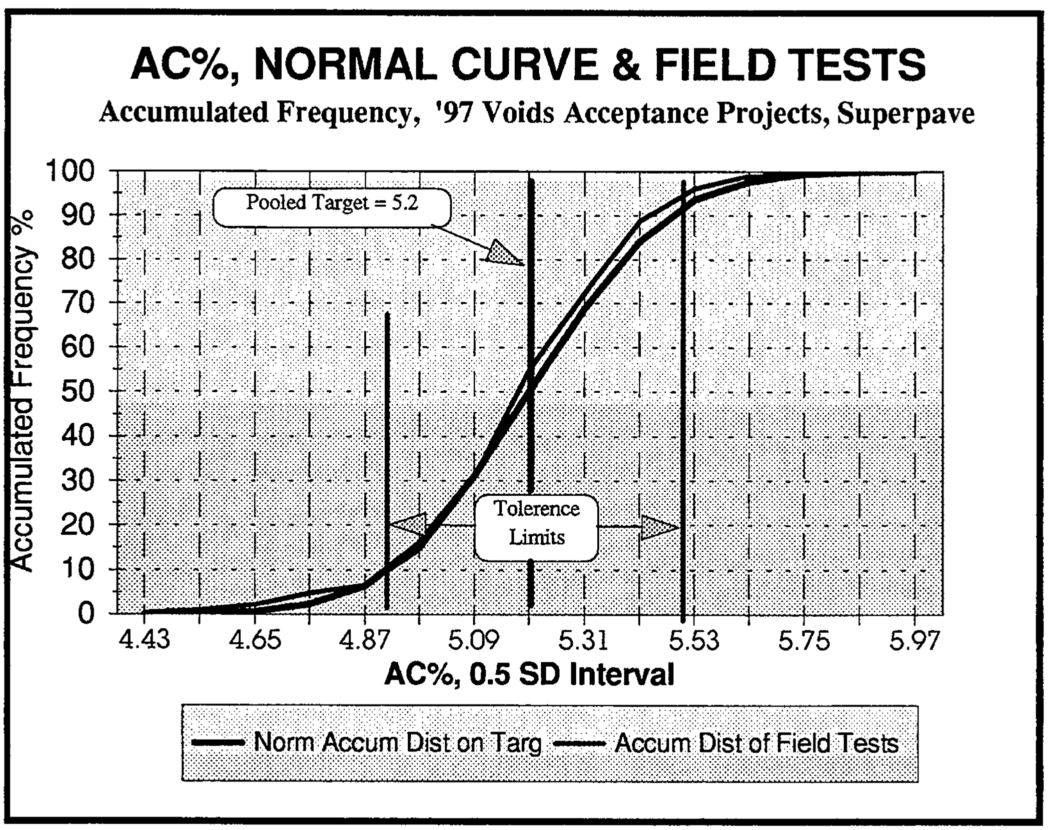

Figure 10

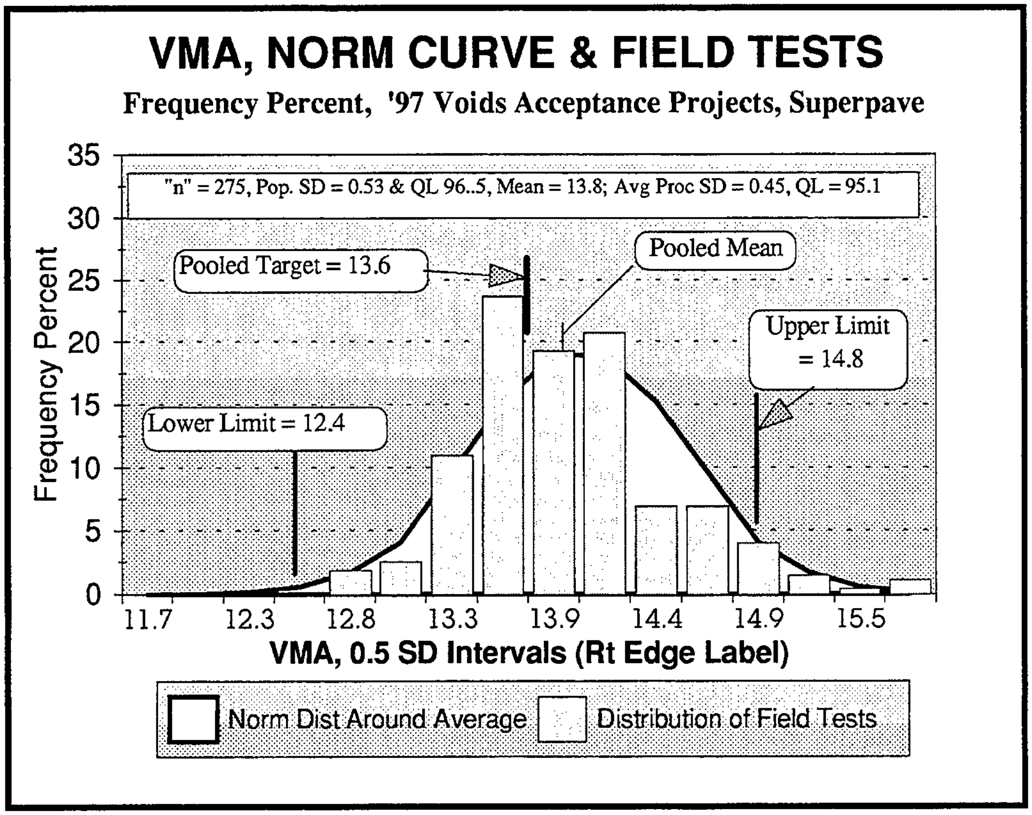

Figure 11

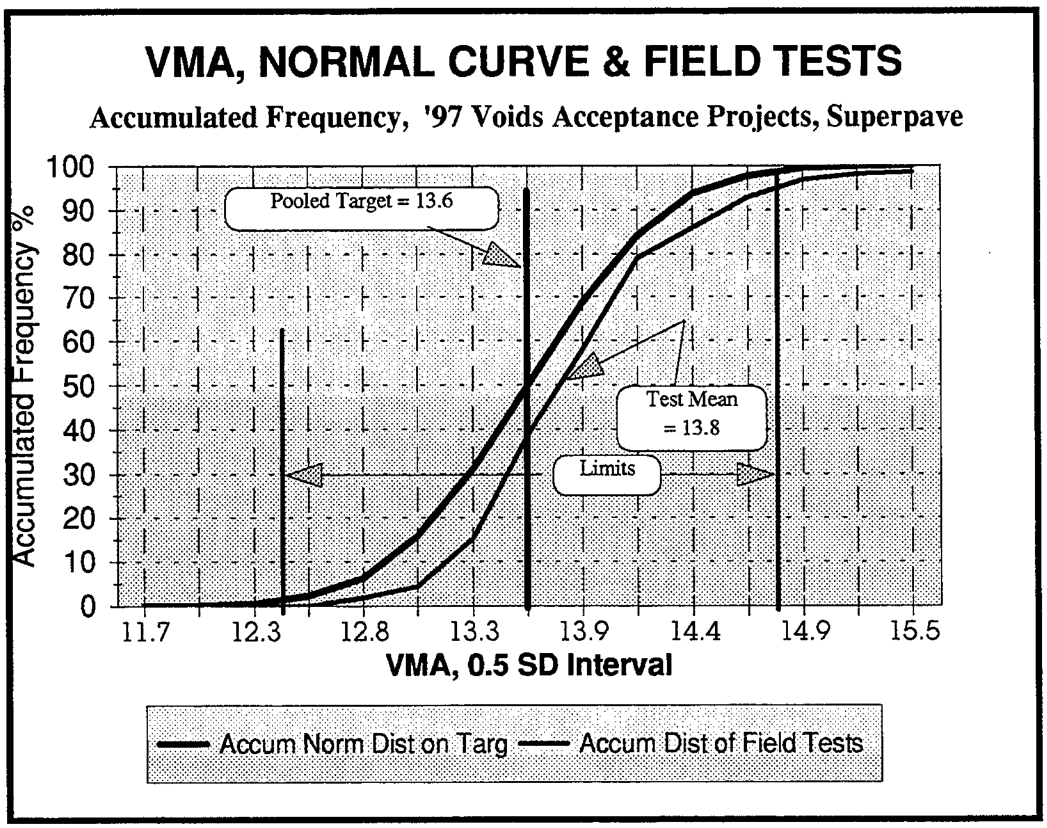

Figure 12

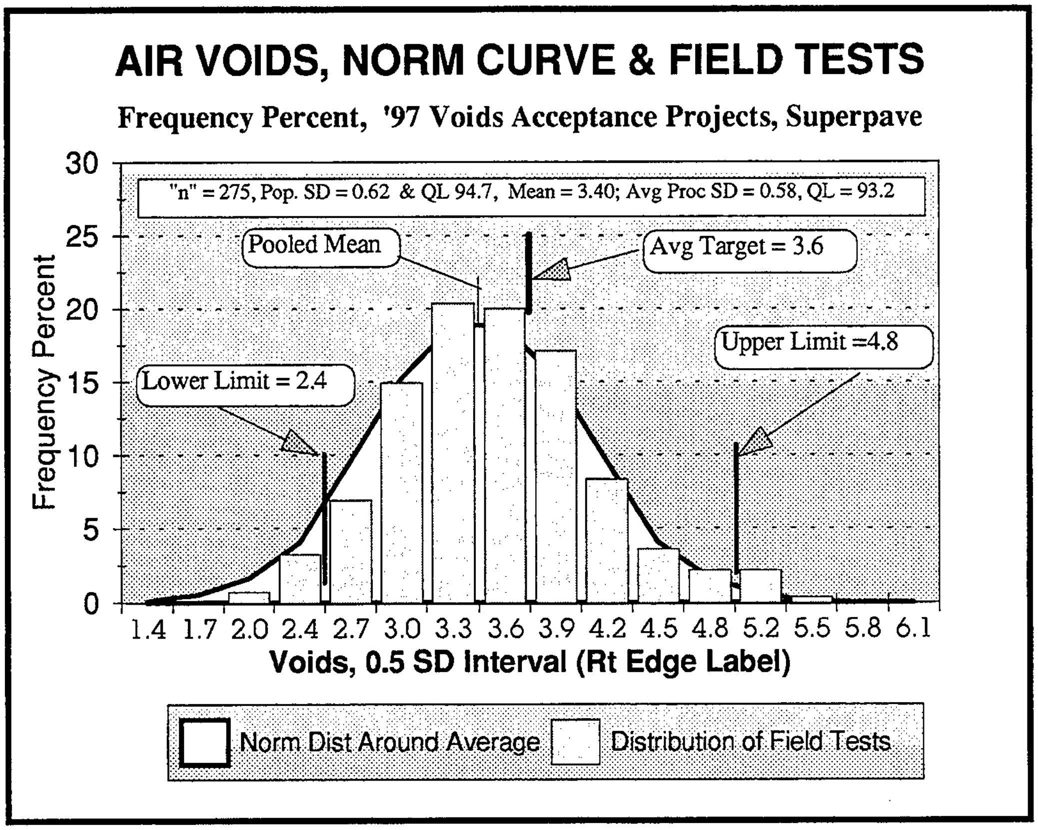

Figure 13

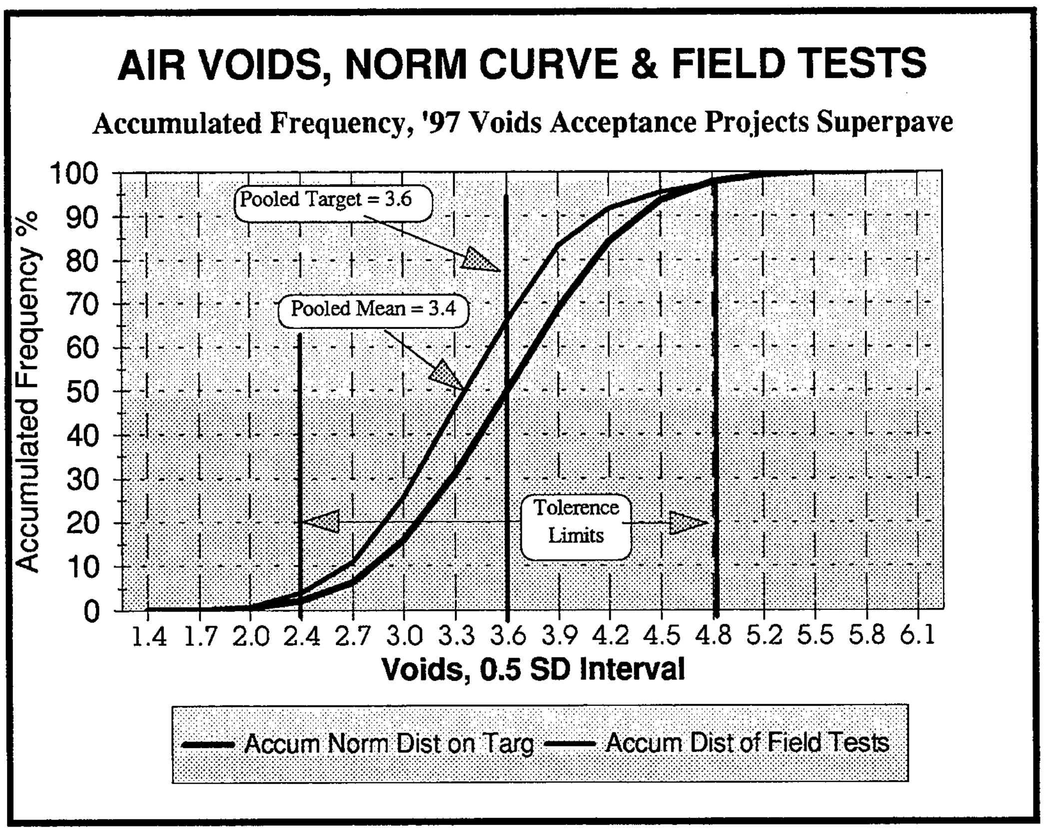

Figure 14

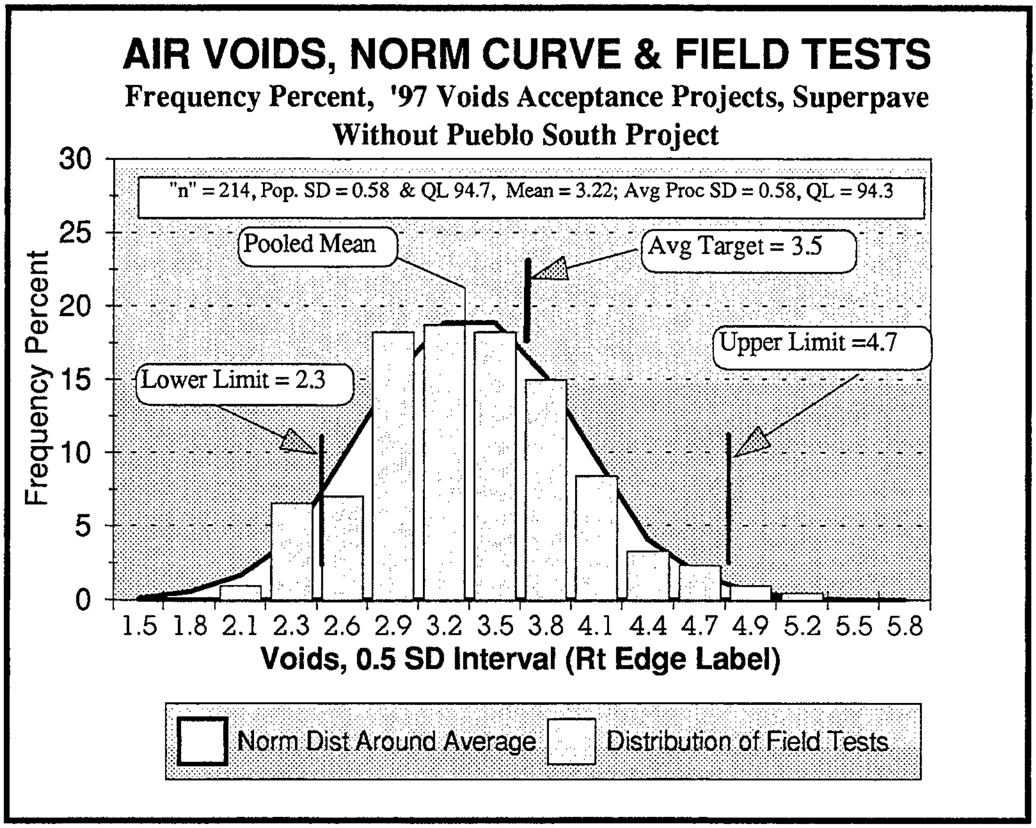

Figure 15

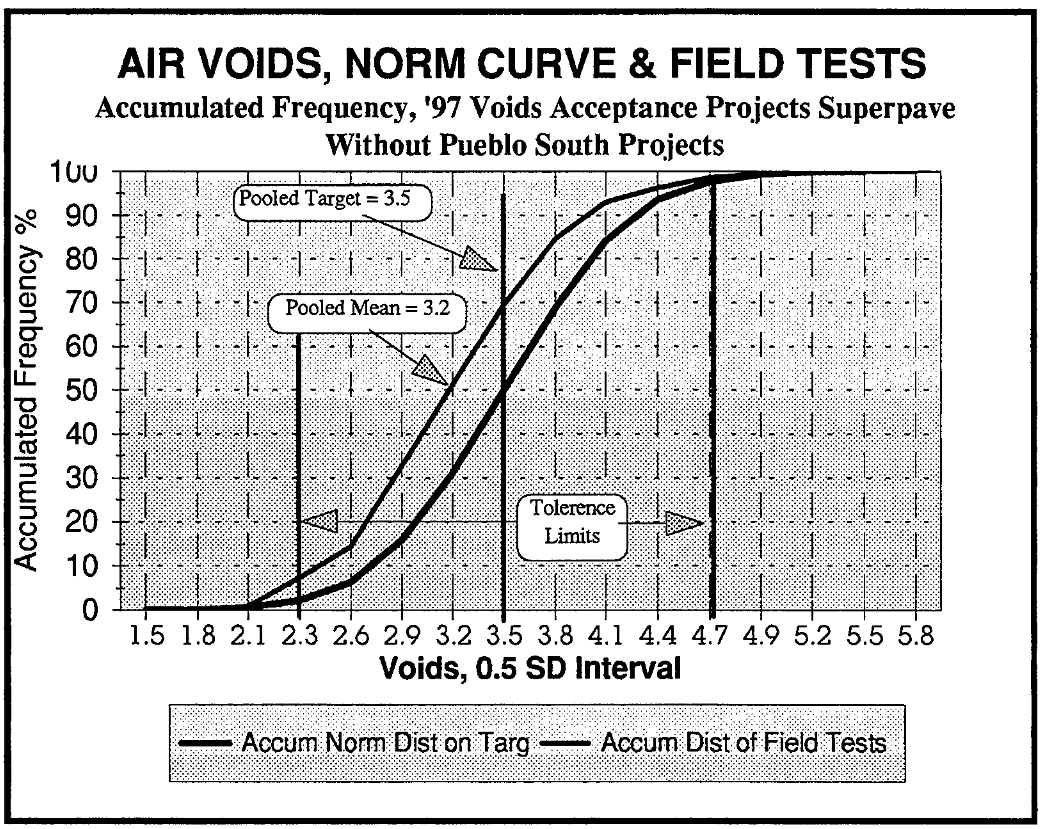

Figure 16

EXHIBIT 1

Revision of Sections 105 and 106
Voids Acceptance of Hot Bituminous Pavement

Exhibit 1 follows, 9 pages, numbered separately.

<<105&106VAHBP-E>>
2-4-98

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

Sections 105 and 106 of the Standard Specifications are hereby revised for this project as follows:

Subsection 105.03 shall include the following:

Conformity to the Contract of all Hot Bituminous Pavement, Item 403, except Hot Bituminous Pavement (Patching) and temporary pavement will be determined by tests and evaluations of asphalt content, voids in the mineral aggregate, air voids and in-place density in accordance with the following:

All work performed and all materials furnished shall conform to the lines, grades, cross sections, dimensions, and material requirements, including tolerances, shown in the Contract.

For those items of work where working tolerances are not specified, the Contractor shall perform the work in a manner consistent with reasonable and customary manufacturing and construction practices.

When the Engineer finds the materials or work furnished, work performed, or the finished product are not in conformity with the Contract and has resulted in an inferior or unsatisfactory product, the work or material shall be removed and replaced or otherwise corrected at the expense of the Contractor.

Materials will be sampled randomly and tested by the Department in accordance with Section 106 and with the applicable procedures contained in the Department's Field Materials Manual. The approximate maximum quantity represented by each sample will be as set forth in Section 106. Additional samples may be selected and tested at the Engineer's discretion.

A process will consist of a series of values resulting from tests of the Contractor's work and materials. Each process will consist of one or more test results. All materials produced will be assigned to a process. A process normally will include all materials produced prior to a change in the job mix formula (CDOT form 43). The Engineer will establish a new process when job mix formula changes occur. The Engineer may separate a process in order to accommodate small quantities or unusual variations.

Evaluation of materials for pay factors (PF) will be done using only the Department's acceptance test results. Each process will have a PF computed in accordance with the requirements of this Section. Test results determined to have sampling or testing errors will not be used.

Any test result for an element greater than the distance 2 x V (see Table 105-2) outside the tolerance limits will be designated as a separate process and the quantity it represents will be evaluated in accordance with subsection 105.03(f). An element pay factor less than zero shall be zero.

In the case of in-place density, the Contractor will be allowed to core the exact location of a test result more than 2 x V outside the tolerance limit. The core must be taken and furnished to the Engineer immediately after notification by the Engineer of the test result. The result of this core will be used in lieu of the previous test result. Cores not taken immediately after notification will not be used in lieu of the test result. All costs associated with coring will be at the Contractor's expense.

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

(a) **Representing Small Quantities.** When it is necessary to represent a process by only one or two test results, PF will be the average of PFs resulting from the following:

If the test result is within the tolerance limits then PF = 1.00. If the test result is above the maximum specified limit, then

$$PF = 1.00 - 0.25(T_0 - T_U)/V$$

If the test result is below the minimum specified limit, then

$$PF = 1.00 - 0.25(T_L - T_0)/V$$

Where:
- PF = pay factor.
- V = V factor from Table 105-2.
- T_0 = the individual test result.
- T_U = upper specification limit.
- T_L = lower specification limit.

If the pay factor of any of the above calculations is less than 0.75 for any element, the acceptance of the work will be evaluated according to subsection 105.03(f).

(b) **Determining Quality Level.** Each process with three or more test results will be evaluated for a quality level (QL) in accordance with Colorado Procedure 71.

(c) **Element Pay Factor.** Using QL, compute PF, as follows: The final number of random samples (Pn) in each process will determine the final pay factor for each element. As test values are accumulated, Pn will change accordingly. When the process has been completed, the number of random samples it contains will determine the computation of PF, based on Table 105-3 and formula (1) below. When Pn is from 3 to 9, or greater than 200, PF will be computed using the formulas designated in Table 105-3. Where Pn is equal to or greater than 10 and less than 201, PF will be computed by formula (1):

$$(1)\quad PF = \frac{(PF_1 + PF_2)}{2} + \left[\frac{(PF_2 + PF_3)}{2} - \frac{(PF_1 + PF_2)}{2}\right] \times \frac{(Pn_2 - Pn_x)}{(Pn_2 - Pn_3)}$$

Where, when referring to Table 105-3:
- PF_1= PF determined at the next lowest Pn formula using process QL
- PF_2= PF determined using the Pn formula shown for the process QL
- PF_3= PF determined at the next highest Pn formula using process QL
- Pn_2= the lowest Pn in the spread of values listed for the process Pn formula
- Pn_3= the lowest Pn in the spread of values listed for the next highest Pn formula
- Pn_X = the actual number of test values in the process

When evaluating the item of Furnish Hot Bituminous Pavement, the PF for the element of In-Place Density shall be 1.0.

Regardless of QL, the maximum PF in relation to Pn is limited in accordance with Table 105-3.

(d) **Element Average Pay Factor.** A pay factor will be determined for all material or work represented by the elements listed in Table 105-2. For the pay estimates, each individual element will have the average pay factor (PF_A), weighted by the quantities, computed as follows:

$$PF_A = \frac{[M_1(PF_1) + M_2(PF_2) + ...M_j(PF_j)]}{\Sigma M}$$

Where: M_j = Quantity of item represented by the process.
Pf_j = The process pay factor.
ΣM= Sum of Quantities, M_1 to M_j (the total quantity).

(e) **Composite Pay Factor.** When there is more than one element for the item, determine the composite pay factor (PF_C) as follows (ΣM used to compute each element PF_A must be numerically the same):

$$PF_C = \frac{[W_1(PF_{A1}) + W_2(PF_{A2}) + ...W_j(PF_{Aj})]}{\Sigma W}$$

Where: W = element factor from Table 105-2.
PF_{Aj} = element average pay factor.
ΣW = sum of the element factors.

As test results become available, they will be used to calculate accumulated QL and PF numbers for each element and for the item. The test results and the accumulated calculations will be made available to the Contractor upon request.

Numbers from the calculations will be carried to significant figures and rounded according to AASHTO Standard Recommended Practice R-11.

(f) **Evaluation of Work.** When the PF_A of every element in a process is 0.75 or greater, the finished quantity of work represented by the process will be accepted at the appropriate pay factor. If PF_A for any element within any process is less than 0.75, the Contractor shall remove and replace the material with specification material at no additional cost to the Department.

When condition red, as described in Section 106, exists for any element, resolution and correction will be in accordance with Section 106. Material which the Engineer determines is obviously defective may be isolated and rejected without regard to sampling sequence or location within a process.

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

Table 105-2
"W" and "V" Factors For Various Elements

ELEMENT	V FACTOR	W FACTOR
Asphalt Content	0.20	10
Voids in the Mineral Aggregate	0.60	20
Air Voids	0.60	30
In-place Density	1.10	40

TABLE 105-3
Formulas For Calculating PF Based on Pn

Pn	**When Pn as shown at left is 3 to 9, or greater than 200, use designated formula below to calculate Pay Factor, PF = ..., when Pn is ≥10 and ≤200, use formula (1) above:**	**Maximum PF**
3	$0.31177 + 1.57878 (QL/100) - 0.84862 (QL/100)^2$	1.025
4	$0.27890 + 1.51471 (QL/100) - 0.73553 (QL/100)^2$	1.030
5	$0.25529 + 1.48268 (QL/100) - 0.67759 (QL/100)^2$	1.030
6	$0.19468 + 1.56729 (QL/100) - 0.70239 (QL/100)^2$	1.035
7	$0.16709 + 1.58245 (QL/100) - 0.68705 (QL/100)^2$	1.035
8	$0.16394 + 1.55070 (QL/100) - 0.65270 (QL/100)^2$	1.040
9	$0.11412 + 1.63532 (QL/100) - 0.68786 (QL/100)^2$	1.040
10 to 11	$0.15344 + 1.50104 (QL/100) - 0.58896 (QL/100)^2$	1.045
12 to 14	$0.07278 + 1.64285 (QL/100) - 0.65033 (QL/100)^2$	1.045
15 to 18	$0.07826 + 1.55649 (QL/100) - 0.56616 (QL/100)^2$	1.050
19 to 25	$0.09907 + 1.43088 (QL/100) - 0.45550 (QL/100)^2$	1.050
26 to 37	$0.07373 + 1.41851 (QL/100) - 0.41777 (QL/100)^2$	1.055
38 to 69	$0.10586 + 1.26473 (QL/100) - 0.29660 (QL/100)^2$	1.055
70 to 200	$0.21611 + 0.86111 (QL/100)$	1.060
≥ 201	$0.15221 + 0.92171 (QL/100)$	1.060

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

Subsection 106.03 shall include the following:

All Hot Bituminous Pavement, Item 403, except Hot Bituminous Pavement (Patching) and temporary pavement shall be tested in accordance with the following program of process control testing and acceptance testing:

(a) **Process Control Testing.** The Contractor shall be responsible for process control testing on all elements listed in Table 106-1. Process control testing shall be performed at the expense of the Contractor. The Contractor shall develop a quality control plan (QCP) in accordance with the following:

1. Quality Control Plan. For each element listed in Table 106-1, the QCP must provide adequate details to ensure the Contractor will perform process control. The Contractor shall submit the QCP to the Engineer at the preconstruction conference. The Contractor shall not start any work on the project until the Engineer has approved the QCP in writing.

   A. Frequency of Tests or Measurements. The QCP shall indicate a random sampling frequency, which shall not be less than that shown in Table 106-1. The process control tests shall be independent of acceptance tests.

   B. Test Result Chart. Each process control test result, the appropriate tonnage and the tolerance limits shall be plotted. For in-place density tests, only results after final compaction shall be shown. The chart shall be posted daily at a location convenient for viewing by the Engineer.

   C. Quality Level Chart. The Quality Level (QL) for each element in Table 106-1 and each required sieve size shall be plotted. The QL will be calculated in accordance with the procedure in CP 71 for Determining Quality Level (QL). The QL will be calculated on tests 1 through 3, then tests 1 through 4, then tests 1 through 5, then thereafter the last five consecutive test results. The tonnage of material represented by the last test result shall correspond to the QL. For in-place density tests, only results after final compaction shall be shown. The chart shall be posted daily at a location convenient for viewing by the Engineer.

2. Elements Not Conforming to Process Control. The QL of each discrete group of five test results, beginning with the first group of five test results, shall be a standard for evaluating material not conforming to process control. When the group QL is below 65, the process shall be considered as not conforming to the QCP. In this case, the Contractor shall take immediate action to bring the process back into control. Except where the cause of the problem is readily apparent and corrected without delay, production shall be suspended until the source of the problem is determined and corrected. A written explanation of actions taken to correct control problems shall accompany the test data and be submitted to the Engineer on the day the actions are taken.

3. Point of Sampling. The material for process control testing shall be sampled by the Contractor using approved procedures. Acceptable procedures are Colorado Procedures, AASHTO and ASTM. The order of precedence is Colorado Procedures, AASHTO procedures and then ASTM procedures. The location where material samples will be taken shall be indicated in the QCP.

4. Testing Standards. The QCP shall indicate which testing standards will be followed. Acceptable standards are Colorado Procedures, AASHTO and ASTM. The order of precedence is Colorado Procedures, AASHTO procedures and then ASTM procedures.

5. Testing Supervisor Qualifications. The person responsible for the process control sampling and testing shall be identified in the QCP. This person must possess one or both of the following qualifications:

   A. Registration as a Professional Engineer in the State of Colorado.

   B. Level II A, B, and C certifications from the Laboratory for Certification of Asphalt Technicians (LABCAT).

6. Technician Qualifications. Technicians taking samples and performing tests must possess the following qualifications:

   A. Technicians taking samples and conducting compaction tests must have Level II A certification from LABCAT.

   B. Technicians conducting process control tests must have Level II B certification from LABCAT.

   C. Technicians determining asphalt mixture volumetrics and strength characteristics must have Level II C certification from LABCAT.

7. Testing Equipment. All of the testing equipment used to conduct process control testing shall conform to the standards specified in the test procedures and be in good working order. Nuclear testing devices used for process control testing of in-place density do not have to be calibrated on the Department's calibration blocks.

8. Reporting and Record Keeping. The Contractor shall report the results of the process control tests to the Engineer in writing at least once per day. The Contractor shall make provisions such that the Engineer can inspect process control work in progress, including sampling, testing, plants, and the Contractor's testing facilities at any time.

(b) **Acceptance Testing.** Acceptance testing is the responsibility of the Department and shall not be addressed in the QCP. The Department will determine the locations where samples or measurements are to be taken and as designated in Section 403. The maximum quantity of material represented by each test result and the minimum number of test results will be in accordance with Table 106-1. The location or time of sampling will be based on a stratified random procedure. Acceptance sampling and testing procedures will be in accordance with the Schedule for Minimum Materials Sampling, Testing and Inspection in the Department's Field Materials Manual. Samples for project acceptance testing shall be taken by the Contractor in accordance with the designated method. The samples shall be taken in the presence of the Engineer. Where appropriate, the Contractor shall reduce each sample to the size designated by the Engineer. The Contractor may retain a split of each sample which cannot be included as part of the QCP.

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

All materials being used are subject to inspection and testing at any time prior to, during, or after incorporation into work. Acceptance tests will be made by and at the expense of the Department, except when otherwise provided.

(c) **Check Testing Program.** The purpose of a check testing program (CTP) is to compare the testing equipment and personnel that will be used according to the Contract. Samples used in the CTP do not need to be from random samples or from the project material. Prior to or in conjunction with placing the first 500 tons of asphalt pavement, under the direction of the Engineer, a CTP will be conducted between acceptance testing and process control testing consisting of five samples of the following elements: Asphalt Content, Voids in the Mineral Aggregate, Air Voids and In-place Density. The average of the absolute differences between the process control and the acceptance testing personnel will be compared to the acceptable limits shown in column 3 of Table 106-2. The CTP will be continued until the acceptance and process control test results are within the permissible ranges shown in Table 106-2.

During production, split samples of randomly selected acceptance control tests will be compared to the permissible ranges shown in Table 106-2. The minimum frequency will be as shown in Table 106-1.

If production has been suspended and then resumed, the Engineer may order a CTP between process control and acceptance testing persons to assure the test results are within the permissible ranges shown in Table 106-2. Check test results shall not be included in process control testing. The Region Materials Engineer shall be called upon to resolve differences if a CTP shows unresolved differences beyond the ranges shown in Table 106-2.

(d) **Target Values for VMA.** After the mix design has been approved and production commences, the first three acceptance tests for Voids in Mineral Aggregate (VMA) will be analyzed to verify and establish a target value for VMA. The Contractor shall make adjustments if required in accordance with the following: The target value for VMA will be the average of the first three volumetric field test results on project produced Hot Bituminous Pavement or the target value specified in Table 403-1 and Table 403-2 of the specifications, whichever is higher.

Whenever a new or revised mix design is used and production resumes, the next three acceptance tests will be evaluated and a target value for VMA will be established in accordance with the above requirements.

(e) **Independent Assurance Testing.** Independent assurance testing for Asphalt Content and In-Place Density will be in accordance with the Department's Field Materials Manual. Independent assurance testing for Voids in the Mineral Aggregate and Air Voids will be performed by the Department's Flexible Pavement laboratory on samples sent from the field at a frequency of one per 10,000 tons.

(f) **Reference Conditions.** Three reference conditions can exist determined by the Moving Quality Level (MQL). The MQL will be calculated in accordance with the procedure in CP 71 for Determining Quality Level (QL). The MQL will be calculated using only acceptance tests. The MQL will be calculated on tests 1 through 3, then tests 1 through 4, then tests 1 through 5, then thereafter on the last five consecutive test results. The MQL will not be used to determine pay factors. The three reference conditions and actions that will be taken are described as follows:

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

1. Condition green will exist for an element when an MQL of 90 or greater is reached, or maintained, and the past five consecutive test results are within the specification limits.

2. Condition yellow will exist for all elements at the beginning of production or when a new process is established because of changes in materials or the job-mix formula, following an extended suspension of work, or when the MQL is less than 90 and equal to or greater than 65. Once an element is at condition green, if the MQL falls below 90 or a test result falls outside the specification limits, the condition will revert to yellow or red as appropriate.

3. Condition red will exist for any element when the MQL is less than 65. The Contractor shall be notified immediately in writing and the process control sampling and testing frequency increased to a minimum rate of 1/250 tons for that element. The process control sampling and testing frequency shall remain at 1/250 tons until the process control QL reaches or exceeds 78. If the QL for the next five process control tests is below 65, production will be suspended.

   After condition red exists, a new MQL will be started. Acceptance testing will stay at the frequency shown in Table 106-1. After three acceptance tests, if the MQL is less than 65, production will be suspended. Production will remain suspended until the source of the problem is identified and corrected. Each time production is suspended, corrective actions shall be proposed in writing by the Contractor and approved in writing by the Engineer before production may resume.

   Upon resuming production, the process control sampling and testing frequency for the elements causing the condition red shall remain at 1/250 tons. If the QL for the next five process control tests is below 65, production will be suspended again.

TABLE 106-1
SCHEDULE FOR MINIMUM SAMPLING AND TESTING

ELEMENT	PROCESS CONTROL	ACCEPTANCE	CHECK (CTP)
CP-42 Determining Asphalt Content of Hot Bituminous Mixtures	1/500 T	1/1000 T[1]	1/10,000 T
CPL-5102, CPL-5103 & CPL-5115 Voids in the Mineral Aggregate	1/1000 T	1/1000 T[1]	1/10,000 T
CPL-5102, CPL-5103 & CPL-5115 Air Voids	1/1000 T	1/1000 T[1]	1/10,000 T
CPL-5106 & CPL-5115 Hveem Stability	1/10,000 T	1/10,000 T[3]	Not applicable.
CPL-5109 Resistance to Moisture Damage (Lottman)	1/10,000 T	according to subsection 401.02	Not applicable.
CP-31 Gradation	1/1000 T	1/10,000 T[3]	Not applicable.
CP-81 Determining Percent Relative Compaction of Bituminous Pavement	1/500 T	1/500 T[1,2]	1/5000 T

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE OF HOT BITUMINOUS PAVEMENT

Notes:

(1) The minimum number of acceptance tests will be at least 5 asphalt content, 5 voids in the mineral aggregate, 5 air voids and 10 in-place density for all projects.

(2) The minimum number of HBP in-place density tests are those made after compaction has been completed and will be in addition to those made in Compaction Test Sections. The acceptance test result for each Compaction Test Section will be an average of the in-place density test results obtained by the Department in that Compaction Test Section.

(3) For information only. These elements are not used to calculate pay factors.

(4) When unscheduled job mix formula changes are made (CDOT 43) acceptance of the elements, except for in-place density, will be based on the actual number of samples that have been selected up to that time, even if the number is below the minimum listed in Table 106-1. At the Engineer's discretion, additional random in-place density test may be taken in order to meet scheduled minimums, provided the applicable pavement layer is available for testing under safe conditions. Beginning with the new job mix formula, the quantity it will represent shall be estimated. A revised schedule of acceptance tests will be based on that estimate.

TABLE 106-2
ACCEPTABLE LIMITS OF TWO LABORATORY TEST RESULTS

ELEMENT	Column 1	Column 2	Column 3
	σ (2 labs testing a split of the same material)	Maximum Difference Split Sample	Maximum Difference Average 5-Test
Asphalt Content	0.25	0.49	0.22
Voids in the Mineral Aggregate	0.60	1.18	0.53
Air Voids	0.59	1.16	0.52
In-Place Density	0.77	1.51	0.67

Notes:

Table 106-2 shows the derivation of the acceptable maximum differences between the averages of five tests performed by two different operators on split samples. Column 1 is the base data showing the historical standard deviation between two operators performing a test on split samples of the same material. Column 2 is the maximum expected difference between two operators performing a test on split samples of the same material. Column 2 is calculated by multiplying Column 1 by 1.96. Column 3 is the maximum acceptable difference between the averages of five tests performed by two different operators on split samples. Column 3 is calculated by dividing Column 2 by the square root of five. In the case of in-place density there may be comparisons between the averages of seven tests performed by two different operators on split samples. The maximum acceptable difference between the averages of seven tests performed by two different operators on split samples is calculated by dividing Column 2 by the square root of seven. Thus if there is to be a comparison of seven in-place density tests performed by two different operators on split samples, then the maximum acceptable difference is 0.57.

Instruction to Designers: Use this special provision in lieu of the standard special provision, *Revision of Sections 105 and 106 - Quality of Hot Bituminous Pavement*, only for *SUPERPAVE* mixes with voids acceptance criteria. The region materials engineer will determine which projects will be subject to voids acceptance criteria. (Delete this instruction from final draft.)

98-1 I-76 Truck Study

98-2 HBP Pilot Void Acceptance Projects in Region 2 in 1997

98-3 1997 Hot Bituminous Pavement QC for Day Pilot Project with Void Acceptance

98-4 Hot Bituminous Pavement QC & QA Project Constructed in 1997 Under QPM2 Specification

REPORTS PUBLICATION LIST
CDOT/CTI Research

96-1 Long-Term Performance Tests of Soil-Geosynthetic Composites
96-2 Efficiency of Sediment Basins: Analysis of the Sedient Basins Constructed as Part of the Straight Creek Erosion Control Project.
96-3 The Role of Facing Connection Strength in Mechanically Stabilized Backfill Walls
96-4 Revegetation of MSB Slopes
96-5 Roadside Vegetation Management
96-6 Evaluation of Slope Stabilization Methods (US-40 Berthod Pass) (Construction Report)
96-7 SMA (Stone Matrix Asphalt) Colfax Avenue Viaduct
96-8 Determinating Asphalt Cement Content Using the NCAT Asphalt Content Oven
96-9 HBP QC & QA Projects Constructed in 1995 Under QPM1 and QPM2 Specifications
96-10 Long-Term Performance of Accelerated Rigid Pavements, Project CXMP 13-006-07
96-11 Determining the Degree of Aggregate Degradation After Using the NCAT Asphalt Content Oven
96-12 Evaluation of Rumble Treatments on Asphalt Shoulders

97-1 Avalanche Forecasting Methods, Highway 550

97-2 Ground Access Assessment of North American Airport Locations

97-3 Special Polymer Modified Asphalt Cement (Final Report)

97-4 Avalanche Detection Using Atmospheric Infrasound

97-5 Keway Curb (Final Report)

97-6 IAUAC - (Interim Report)

97-7 Evaluation of Design-Build Practice in Colorado (Pre-Construction Report)

97-8 HBP Pilot Void Acceptance Projects Completed in 1993-1996 (Interim Report)

97-9 QC & QA Projects Constructed in 1996 Under QPM2 Specifications (Fifth Annual Report)

97-10 Loading Test of GRS Bridge Pier and Abutment in Denver, CO

97-11 Faulted Pavements at Bridge Abutments

95-1 SMA (Stone Matrix Asphalts) Flexible Pavement
95-2 PCCP Texturing Methods
95-3 Keyway Curb (Contruction Report)
95-4 EPS, Flow Fill and Structure Fill for Bridge Abutment Backfill
95-5 Environmentally Sensitive Sanding and Deicing Practices
95-6 Reference Energy Mean Emission Levels for Noise Prediction in Colorado
95-7 Investigation of the Low Temperature Thermal Cracking in Hot Mix Asphalt
95-8 Factors Which Affect the Inter-Laboratory Repeatability of the Bulk Specific Gravity of Samples Compacted Using the Texas Gyratory Compactor
95-9 Resilient Modulus of Granular Soils with Fine Contents
95-10 High Performance Asphalt Concrete for Intersections
95-11 Dynamic Traffic Modelling of the I-25/HOV Corridor
95-12 Using Ground Tire Rubber in Hot Mix Asphalt Pavements
95-13 Research Status Report
95-14 A Documentation of Hot Mix Asphalt Overlays on I-25 in 1994
95-15 EPS, Flowfill, and Structure Fill for Bridge Abutment Backfill
95-16 Concrete Deck Behavior in a Four-Span Prestressed Girder Bridge: Final Report
95-17 Avalanche Hazard Index For Colorado Highways
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