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1997 HBP QC For Pay Pilot Projects With Void Acceptance

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13. ABSTRACT (Maximum 200 words)

CDOT's first two HBP projects using contractors' quality control (QC) tests as basis of payment. QC tests for void analysis were required. Two levels of verification were used: Results of random split samples (VT's) by the contractor and by CDOT were compared. Contractor VT's were compared to QC results. Comparisons were by statistical *F-test* and *T-test*. **Conclusions**: Contractors VT sets were within limits. The procedures used are workable. QC tests with statistical verification can bu used for pay. The number of VT's to QC's can safely be 1 out of 8. Give more weight to air voids - less to VMA in pay calculations. Consider voids filled with asphalt when making changes in the job mix formula. **Implementation:** Use *F-test & T-test* to verify that contractor's QC tests for pay are accurate and unbiased. Give more weight to AV and less to VMA in composite PF formula. More training is required for industry and CDOT on volumetric property testing Consider effects on VFA when making field changes in the job mix formula.

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1997 HOT BITUMINOUS PAVEMENT QC FOR PAY PILOT PROJECTS, WITH VOID ACCEPTANCE

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1997 HOT BITUMINOUS PAVEMENT QC FOR PAY PILOT PROJECTS, WITH VOID ACCEPTANCE

BACKGROUND OF QC FOR PAY AND VOID ACCEPTANCE

CDOT began their quality control and quality assurance (QC&QA) program for hot bituminous pavements (HBP) in 1992 when they began a three-year pilot program. It was essentially completed in 1994, but a few projects were held over and completed in 1995. The Pilot specification computer software was designated QPM 1(1); also, the term used herein to identify that series of projects. In 1994 a revised, updated specification, designated as QPM 2(2) was written. It was used on several projects completed in 1995 and all regular HBP projects completed in 1996 through 1998. Reports have been written for each of the six QC&QA years [3 to 8], 1992 through 1997, and are available from the CDOT library.

A long-range goal of the QC&QA program was to base contract payment on Contractors' QC tests. After five years in the program, most involved personnel believe QC tests reliably reflect the quality of construction, just as CDOT's QA tests do. This being the case, QC tests should be satisfactory for pay calculations. Where used for pay, QC tests must be randomly verified by CDOT to assure they are accurate and unbiased. By adopting QC tests for pay, a reduction in CDOT field testing should be possible. On Federal Aid projects, regulations permit QC for pay (QCFP), provided certain guidelines are met. In 1996, a concerted effort was made by CDOT and industry people, with support from FHWA representatives, to develop a pilot QCFP specification for HBP.

During the period, 1992 to 1996, many rapid changes were taking place in asphalt pavement mix design and construction technology. CDOT committed to keep up with technology changes. They concentrated on two major advances: (1) Adoption of the Superpave (SP)[9] mix-design procedure and (2) Voids acceptance (VA) of field mixtures based on the laboratory volumetric properties during construction. Under VA, asphalt content and in-place density remains as acceptance elements, but ***field*** acceptance of gradation is dropped. A pilot VA program began in 1992, and by 1996, nine projects had been completed [10] and reported. Three more were completed in 1997 and reported [11]. At the end 1996, only five SP projects had been completed, including three VA/SP projects. In 1997, 44 of 57 QC&QA jobs advertised for bid were **full** SP projects, including performance graded (PG) asphalt cement **and** SP aggregate grading designations.

While developing the pilot QCFP specification (in late 1996), some CDOT engineers wanted to combine the three technologies, QCFP, VA and SP design, into a single pilot specification. Industry members and others expressed concern over this approach, fearing this would introduce too many new things at once. Contractors, and private laboratories, were just beginning to get SP compactors and had yet to do any significant amount of field control testing for VA. Until then, CDOT did all field testing for voids properties on VA projects. Their tests were being used for plant control ***and*** acceptance. CDOT was just completing the switch from the Texas Gyratory to the SP compactor for mix design. Under the QCFP concept, for the first time, contractors would be required to make QC tests for voids properties. In addition, the new SP lab compactor would be specified along with PG asphalts and SP gradations.

CDOT, with assistance from industry, addressed the various concerns and wrote a pilot QCFP specification (Exhibit 1, attached) for the 1997 construction season. Standard QC&QA HBP specifications [2] were modified to make QC tests (instead of CDOT acceptance) the basis of payment for the usual three elements, asphalt content, in-place density and gradation. Contractors have plenty of experience making QC tests on these three elements and did not foresee problems here. However, they were concerned about doing percent air voids (AV) and voids in the mineral aggregate (VMA) tests for pay. This stemmed from their lack of familiarity with SP and VA test procedures. CDOT addressed this in the pilot by not assessing ***disincentive*** payments for Pay Factors of less than 1.0 for voids properties. Adjustments were required to bring properties within acceptable limits, however. As motivation, a special ***incentive*** pay formula, based on quality level analysis (QLA) of VMA and VA, was included.

THE QCFP PILOT SPECIFICATION

CDOT's standard QC&QA specifications [2] have stringent requirements for the contractors' QC program. The QCFP pilot maintained these requirements. In addition, a procedure was included for verification testing to assure QC tests would correctly represent the work. During development of the QCFP specification, plenty of discussion took place about the number of CDOT verification tests to be taken in relation to the number of QC tests. To avoid duplication of effort, only the absolute minimum number of verification tests should be taken. However, in this first effort, the ratio of CDOT tests to QC was kept high for a greater level of confidence and to provide more data for post construction analysis.

Under QC&QA specifications, all contractor and CDOT tests are randomly selected. For this pilot, one verification test (VT) is randomly selected by CDOT from each defined element strata (from the stratified random sampling schedule). Each VT is split and tested by the contractor and CDOT (for in-place nuclear density, the same spot is tested by each) and reported to the engineer. The sampling ratio of VT to QC ranges from 1:1 for in-place density, to 1:3 for gradation and voids properties, to 1:7 for asphalt content.

Standard statistical ***F-test*** and ***t-test*** procedures [12] are used to verify that the various sets of test results are statistically similar within defined probabilities. The ***F-test*** provides a method for comparing the variances (standard deviation [SD] squared) of two sets of data. Differences in means are evaluated by the ***t-test***. Comparisons in the field are continuous, as results became available.

CDOT developed a spreadsheet computer program that does the calculations and provides the results as test results are entered accumulatively for each element. Two sets of test values from the same process obtained by nearly identical procedures will usually have different means and standard deviations. Such differences can be by random chance alone. The program calculates means and variances, then determines the probabilities that the two sets of data are tested by the same procedure. Large probability numbers, up to 100%, show good agreement in sampling and testing procedures on similar materials. When probabilities are low (1% or 0.5%) that the differences are not by random chance, flawed procedures may have been used in obtaining one or both data sets. If this happens, specified actions are required by the engineer.

The ***F-test*** and ***t-test*** are used to compare contractor VT's with CDOT VT's on running five-sample splits. As a check testing program, the first five VT pairs are compared and must be acceptable before the work can continue. If not acceptable, the check testing phase continues, after corrective actions, until the evaluation shows acceptable results. Two levels of probabilities are used, 5% or less warns of potential problems and 1% or less, requires corrective actions.

During routine production, the contractor's VT's are compared with the rest of the QC tests from which the VT's were randomly selected. Again, two levels of probabilities are used, 5% or less gives a warning, 0.5% or less, is not acceptable. A running, accumulated calculation is made for information, but the acceptance decision is made only when all tests have been completed. If the comparison is acceptable, the contractor is paid, incentive or disincentive, based on quality level analysis [13] (QLA) of all QC tests (including contractors' VT's). If they are not acceptable, payment is based on CDOT's VT results.

THE 1997 PILOT QC FOR PAY PROGRAM

Initially, CDOT hoped that each region would let two QCFP projects for the 1997 season. After further evaluation, management determined that SP adoption had the highest priority and efforts would be concentrated there. However, to start the QCFP program, Region 6 volunteered two projects.

The projects, (1) I 25, Hampden - South, and (2) Colorado Boulevard, Mississippi Avenue to Martin Luther King Boulevard, were let to contract and completed by fall. A single contractor, Kiewit Western Company was the successful bidder on both projects. This report summarizes the data provided by the contractor and CDOT field personnel. Particular emphasis has been placed on areas where the greatest concerns were expressed during development of the QCFP pilot.

The QCFP program will pause for 1998. It is expected to resume in 1999 under a revised QCFP specification (now being written) that will incorporate the three technologies referred to above, namely QCFP, VA and SP. In 1998, the VA pilot program (using full SP) will continue at an increased rate under a revised specification, now in use, (see Reference 11, Exhibit 1) that closely parallels QPM 2. This specification requires full QC testing for volumetric properties. As with previous VA projects, field acceptance testing of aggregates is not included. However, QC sieve analysis testing and reporting are required by the contractor, but not for pay. The specification evaluates four elements by QLA. PF's are calculated by the same formulas as in QPM 2. As in the previous VA pilots, the element "W" factors are 0.1 for AC%, 0.4 for density, 0.2 for VMA and 0.3 for AV. The QPM 2 "W" factors are 0.3 for AC%, 0.5 for density and 0.2 for gradation. "W" is a relative weighting factor applied to the element PF's when calculating the item composite PF.

SUMMARY AND ANALYSIS OF THE 1997 QCFP DATA

The first page of Table 1 separately lists the field data from the two projects. Columns headings identify data in rows across from the listings at left. Cells are shaded if not applicable. Data is not available where "NA" shows. Elements in each process are grouped with the normal QPM 2 elements listed first, followed by AV and VMA, as pay elements. Percent voids filled with asphalt (VFA) has been added for information.

The SP procedure by CDOT includes VFA with a ***design*** parameter of 65-75 for medium-to-heavy traffic. Not specified for the projects, but used here to calculate QL, was a target of 70 and a tolerance of 7.0. CDOT has elected not to specify VFA as field acceptance criteria, because it is redundant. VFA = [(VMA - AV)/VMA] x 100. It is controlled by adhering to the target of 4% air voids and the specified minimum VMA. AV and VMA have a linear relationship to VFA. Figure 1 shows this where the VMA target is 14.0 (lowest ***design*** target allowed for grading S) and the AV target is 4.0. For these targets, if production is controlled such that the PF is maintained at 1.0, or higher, ("n" = 15), there is only a slight possibility of VFA being outside the recommended range. The effect of varying or maintaining AC% is not shown in Figure 1. Field adjustments to the job-mix formula can easily cause VFA to rise above 75. For mix designs and checks, the Central Laboratory routinely calculates and reports VFA. In Table 1, VFA has been calculated and reported to aid in understanding the relationships and to show levels of field conformity to the design parameter.

QL can only be calculated when "n" is three or larger, so in Table 1 it is not shown for processes with less than two tests. There are columns for PF's for voids properties (special for these projects) and for the usual QPM 2 elements. The actual incentive/disincentive (I/D) dollars paid for the various process elements is shown; it is the combination of the two PF's. Contractors' code is used by CDOT to identify the various HBP contractors. Grading S (SP 3/4" nominal) was used on both projects. "F" was added here to show the plotted grading curves were above the maximum density line.

As stated above, if the contractor's VT and QC tests do not compare within a probability of 0.5%, the process element PF must be based on CDOT VT's. The CDOT QL's are listed in Table 1 for comparison to the QC QL's. For both projects the weighted average CDOT QL for QPM 2 elements was 88.1, compared with the contractor's 94.1. By CDOT, the I/D$ would have been close to zero, compared with $64,923 by the contractor's QL. For voids properties, by CDOT, the I/D$ would have been about $25,000, compared with $18,205 by the contractor's data. Contractor pay was almost $70,000 more than if based on CDOT tests. ***F*** and ***t*** test results show the differences in means and SD's, and consequently QL, could have occurred by random chance within the probability levels stated. Examination of element probabilities shows the lowest values, for contractor QC's to VT's, was for density on process No. 2, Project 11755 (See Table 1, Figure SS-1, and Figures 4 and 5). Values were 0.064 for ***F*** and 0.018 for ***t***, close to the 0.5% critical value, but OK.

Figure SS-1 is a copy of the spreadsheet for the above process. Compare the SD's and means. For the contractor and CDOT VT sets, the match is good (0.02 difference in SD's and 0.05 in means). The match is not as good for the QC and contractor's VT (0.19 difference in SD's and 0.35 in the means), but the probabilities are acceptable. In this density process, the contractor's verification test No. 11 was 89.7, more than 2 x V below the lower limit of 92.0. V is approximately one historical SD, and is 1.1 for density. Any element test value more than 2 x V out of limits is made into a separate one-sample process and evaluated by a special formula. In Figure SS-1, this test has been removed from the process (also, the accompanying CDOT split, which compared favorably). The spreadsheet is not shown with the test included, but Figure 2 graphically portrays the ***F*** probability curve with No. 11 included (where SD difference was 0.40). At test No. 20 the probability dropped to 0.005 and at No. 24 to below 0.001. Figure 4 is a plot of the ***F*** probability calculations from Figure SS-1 (without No. 11) and shows the dramatic difference in line slopes with the single low, outlying value removed.

The second page of Table 1 has the processes grouped by elements, first those in regular QPM 2, and second, those associated with VA. A weighted average and total line is shown for each element. Summarized at the bottom of the page are the six elements for the two projects. Below that summary is a smaller box with information for QL, PF and I/D$. Shown, also, is comparable information from the 1997 regular QPM 2 projects, the 1997 VA projects, and by the 1998 VA criteria. The I/D values in the Table 1 summary show that if the two QCFP projects had been evaluated under the 1998 VA formulas, a *disincentive of* $15,070 rather than an *incentive* of $83,127 would have been assessed. Also note that the Region 2 VA projects, by 1998 criteria, would have an incentive of $69,720 rather than $201,468. For the QCFP projects, the difference in pay is related to the special incentive PF's for the VMA and AV (**with no negatives**), while the usual elements had higher QL's than historical averages. For the Region 2 VA projects, the difference is because the pay-factor formulas used (similar to QPM 1) were more favorable to the contractor than the QPM 2 formulas used in 1998 VA specifications.

Table 2 has a more comprehensive array of data from the various type of HBP projects constructed since 1992. It includes information on the number of tests, on SD, QL, PF's by QPM 1 (or VA) and QPM 2. For QCFP, looking first at density, the SD is considerably below the QPM 2 averages, and the VA Superpave values. From Figures SS-1 and SS-5, it can be seen that CDOT's VT's also have SD's lower than typical. The QL is higher than any other density QL's above in the column. Superpave void acceptance projects are displaying a trend toward lower SD's for density (while mean values are staying about the same, or lower). It is too early to say whether the 0.61 SD value is unrealistically low. The AC content values appear reasonable in comparison to QPM 2, and better than previous VA projects. The VMA SD and QL values are in line with previous VA data. All the VMA values are high, showing the tolerance limits and job-mix targets are easy to meet. Either the tolerances should be tightened or the "W" factor decreased, or both.

Air voids element values for QCFP show low compliance with specifications. SD is higher than on the VA projects, and QL is much lower. On previous VA projects the universal target of 4.0% has proved difficult to meet. On two of the 1997 Region 2 VA projects the target was changed to 3.5%. Without this change, the average 1997 AV QL might have been lower. On the QCFP projects, after some significant problems at startup (see 11755 Process 1 and 11600 processes 1 & 2), the air voids were close to target, but the SD's were high. The air voids test is really a calculation from two test procedures; bulk specific gravity on laboratory-compacted specimens and maximum theoretical specific gravity (Rice). Much training and practice are required for skills to be developed for these tests. CDOT laboratory results show they have developed the necessary skills. Their average air void SD on their VT's was 0.64, not far above the average of 0.56 for the SP pilot VA projects. This shows that most of the QC variability was probably related to testing rather than production. As private labs and contractors gain experience, their values are expected to fall more in line with CDOT's.

THE *F-TEST* and *t-TEST* PROCEDURES and GRAPHS of PROBABILITY DATA

Figures SS-1 through SS-8 are copies of the spreadsheets used for calculating probabilities for density, AC%, VMA and AV elements on the two projects. (Only the major processes are shown, spreadsheets for the startup processes were made by field personnel, but to avoid clutter, are not shown here). Spreadsheets were also prepared for each specified sieve on each project. All met the ***F*** and ***t*** criteria easily. Field gradations will not be in VA specifications, so no further reference will be made.

In the SS series of figures, three major sections are to the right of the test data fields, each with two columns of probability calculations. Figures 2 through 25 are graphic plots of the probability values from the spreadsheets. On the spreadsheets, the first ***F*** and ***t*** columns compare contractor VT's with CDOT's based on running 5-sample splits; the data is plotted on the figures as the medium weight line.

The second pair of ***F*** and ***t*** columns is for information only and shows trends in the accumulative VT comparisons. In the Figures, the lightest weight line represents this pair of columns. In searching for problems when the running 5-sample splits are not acceptable, the columns may be useful. For information only, the third pair of columns provides an accumulated analysis of the QC to Contractor VT comparison. On the graphs, this plot is represented by the heaviest line. At completion of the process, based on all the tests (last data entries), a decision is made whether to pay by QC or CDOT VT data. Values in the columns show trends and should warn the contractor in time to correct problems.

In the first pair of columns, for all elements on both projects, only three cases of **Alerts** (all for low ***t*** values) on VT for splits after test No. 4 are shown, (tests 3 and 4 are for information only). They were as follows:

(1) For density on 11755 (Figure SS-1 and Figure No 5). This **Alert** at pair No. 18 appears to have been a random anomaly. The running set of five tests had very low, similar SD's. The formula predicts that the means should be nearly identical, but they were slightly different. Without corrective actions, this alert corrected itself,

(2) For the last pair of split VT's for AC% on 11755 (Figure SS-2 and Figure 7.). No corrective action was required, as this was the last split pair, and

(3) For air voids on 11600 (see Figure SS-7 and Figure 23). This **Alert** was for pair No. 5. Corrective actions were taken and resulted in satisfactory probabilities for the rest of the sets.

For Figures 2 through 25, paired graphs for individual elements were plotted from spreadsheet probability data. ***F*** data is on the top figure and ***t*** data on the bottom figure. The pairs are plotted from calculations on the same sets of test values. Above the upper graph is the pertinent statistical data for each pair of graphs. On page 5, above, Figures 2 and 4 are discussed, relating to the effect of a single outlying density value in a process. By examining the block of data above the two graphs, it is apparent the outlying density test SD's affected the SD much more than the mean. In Figures 2 and 4, the two bold line plots for SD's (***F***) are very different, while the bold line plots for means (***t***) are similar (Figures 3 and 5).

REDUCING THE RATIO OF VERIFICATION TESTS TO QC TESTS

As part of this study, an experiment was done to simulate the effect on probability calculations if the number of VT's to QC's were cut in half. AC% was not evaluated because a 1:7 ratio was used and it is not expected the ratio will decrease below that. On Figures SS-1, SS-3 and SS-4 (for density, VMA and AV respectively), the VT data has been blocked off by light horizontal lines into stratas to create 1:7 ratios. This gives two to four VT's per strata. By random numbers, one was selected (heavier shading) for each strata. The other VT's were added to the QC strata and the corresponding CDOT VT values were discarded.

New spreadsheets were developed for this changed QC format and the reorganized data entered. Prints of these sheets are not included, but are in the files. Figures 6 & 7, 12 & 13, and 16 & 17 (for density, VMA, and AV, ***F*** and ***t*** calculations respectively) are plotted from the data in this experiment. In none of the three cases would the action decisions have changed had this reduced VT schedule been carried out. This suggests that the ratio of VT to QC tests can be similar to the ratio represented by this experiment without a major effect on QC acceptability decisions.

EXPERIMENT TO VERIFY CRITICAL PROBABILITY LIMITS

It has been noticed that where there are significant average differences between means or between SD's for two sets of data, the rate of probability descent is steep and rather constant. This relates to the QC to contractor's VT comparisons. As 'n' increases, the probabilities get lower and lower, though the differences in means and SD's remain about the same. The question arose whether the critical value (0.5%) for action on VT to QC comparisons should be changed as "n" increases. It was also suggested that calculating probabilities based on running sets of 10 and 20 VT's be evaluated to see if this gave a more reasonable method for acceptability decisions.

Figures 26 through 33 represent several computer-generated sets of data used to test the above questions. Mean and SD differences are as noted on each figure. In this experiment, SD, mean and "n" are the computer variables, and were purposely selected as shown. Three small graphs are included in each figure. Represented on the cumulative graph is the current spreadsheet calculation method for the QCFP projects. Running sets of 20 values (for the same groups) are shown on the next graph. The third graph shows running sets of 10 values (same groups). Figure 26 and 27, for asphalt density, compare sets of data about as different in SD's as they can be and still be acceptable (for "n" greater than 30). In Figures

28 and 29, data sets are shown with unacceptable differences after "n" equals 45 for SD's and 23 for means.

Figures 30 and 31 are for computer-generated random sets for air voids. Note these become unacceptable after 27 tests. We can say with confidence, after 27 tests, only a 0.5% probability exists that the differences in SD's and means are by random occurrence. Note that at test No. 18, the lines started upward. More values were needed to be sure of the trend. Finally, Figures 32 and 33 show plots for two sets of data related to asphalt content. The probability for the means difference becomes unacceptable at test No. 38.

The ***F-test*** formula for comparing SD's is independent of the means difference. Two sets of data with very different means can still have very similar variances and be acceptable for SD comparisons. The ***t-test*** formula includes variance **and** mean values for the two sets, so when comparing the means, SD has a major effect. Where the SD difference is small, only a small difference in means is allowable.

Acceptable average differences in SD's and means cannot be stated. If this were the case, average differences could be used rather than statistical calculations. Peaks and valleys in the lines are caused by the randomness of the numbers. Another set of values with the same differences would create plots with different peaks and valleys, but show similar slopes. In the computer generated groups, calculating by running sets of either 20 or 10 gave no better information for decisions than using accumulated data. The SD's for smaller sets of numbers vary in relation to the true SD for the population divided by the square root of "n" for the smaller sets. The best, most reliable calculations can be made by using all data available. We conclude from this experiment, the method of calculating the ***F*** and ***t*** probabilities and selection of critical values should remain as used in the QCFP pilots, at least for now. If the ratio of VT to QC is reduced, a distinct downward trend in probability values might become an issue only for very large tonnages (large "n"s).

CONCLUSIONS

(1) Contractors' QC tests can be used for pay determinations with verification procedures similar to those used on the 1996 QCFP projects. For the regular QPM 2 elements, the contractor's average QL of 94.1 was much higher than the three-year average QPM 2 QL of 91.0. However, during this period, nine annual QL averages by individual contractors were more than 94.0 (for tonnages equal to or greater than on these projects). So values as high as 94.1 should be expected. CDOT's average QL of 90.0 is not statistically different from the contractor's 94.1. Both average QL's are composites of the element QL's calculated from individual sets of test values. The sets were evaluated by ***F*** and ***t*** tests. It was found the differences could have been random occurrences, within the probabilities stated.

(2) The ***F*** and ***t*** test procedures used for these projects to compare sets of test values were workable. Based on differences in SD's and means, the program adequately differentiated between acceptable

and unacceptable comparisons. Errors in the spreadsheet program used in the field have been corrected and a few other minor changes made. Other, easier to use, program formats could be developed using ***F*** and ***t*** probability calculations.

(3) VMA criteria were easily met, based on job-mix targets, resulting in a QC average QL of 94.8. This agrees favorably with values developed by CDOT on previous VA projects. On these projects, CDOT's QL was 98.1. SD's compare favorably with the VA projects. The tolerances should be tightened to $\pm$ 1.0% and the W factor reduced from 0.2 to 0.1.

(4) AV criteria were not satisfactorily met. The average value was 4.05, only 0.05 above the target. Nevertheless, the average SD was 0.84 (compared with the VA/SP average of 0.56), resulting in a QL of 76.4 compared to the VA/SP average of 90.7 (and CDOT's VT QL of 90.5). The special PF formula did not provide enough incentive to override the production and testing problems incurred by the contractor. Because CDOT's values compare favorably with previous VA projects, we conclude that most of the contractor's problems were in testing procedures (probably in making specimens and the specific gravity tests). We believe that practice and attention to detail will solve the testing problems. Importance of this element warrants a higher W factor.

(5) VFA averaged 72.6, within the 65-75 limit, but with a QL of only 79.8. The low QL was related to the high AV standard deviations. VMA and AV are the variables used to calculate VFA; the VMA criteria were satisfactory.

(6) The number of verification tests in relation to the QC tests can be safely reduced, up to half, without significantly affecting decisions based on the probability values that compare sets of data.

RECOMMENDATIONS

(1) Use the quality level analysis approach for the pilot QCFP projects planned for 1999. These projects should have as pay elements, AC%, in-place density, VMA and AV, and be designed by the SP procedure. The AV test needs particular attention. Industry will gain experience in QC voids-analysis testing on the Phase 2 VA projects planned for 1998. Based on the proficiency proved by CDOT laboratories, it is expected QC air-void testing will be acceptable for the 1999 QCFP pilots.

(2) Decrease the W factor for VMA to 0.1. VA/SP historical average SD is 0.46. Decrease the tolerance to $\pm$ 1.0, two historical SD's for a seller's risk of 5%. Leave V at 0.6, 1.2 historical SD's 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, two historical SD's for a seller's risk of 5%. Increase V to 0.7, 1.2 times the historical average SD for a seller's risk of 5%.

(4) For the 1999 pilot QCFP projects, continue the use of the F and t test procedures to verify the contractors' QC tests. The current spreadsheet is workable and has been updated and corrected. It may be more cumbersome than necessary; so consider revisions. The most difficult parts of verifying the QC tests were the methods described in the 1997 pilot specifications for setting up the random sample selection schedules. These, along with the actual mechanics involved, need to be reviewed carefully.

(5) Pay more attention to the VFA parameter. It is not recommended that it be a pay element. Nevertheless, calculate and consider it routinely when setting up the job mix formulas in the field. VFA is affected by the targets selected for AC%, VMA and AV.

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6. HBP QC&QA Projects Constructed in 1995 Under QPM 1 and QPM 2 Specifications, (1996 fourth annual report by Bud A. Brakey, Colorado Department of Transportation, 4201 East Arkansas Avenue, Denver, CO 80222.), Report No. CDOT-R-96-9.

7. HBP QC&QA Projects Constructed in 1996 Under QPM 2 Specifications, (1997 fifth annual report by Bud A. Brakey, Colorado Department of Transportation, 4201 East Arkansas Avenue, Denver, CO 80222.), Report No. CDOT-R-97-9.

8. HBP QC&QA Projects Constructed in 1997 Under QPM 2 Specifications, (1998 sixth annual report by Bud A. Brakey, Colorado Department of Transportation, 4201 East Arkansas Avenue, Denver, CO 80222.), Report No. CDOT-R-97-4.

9. "Superpave™ Level 1 Mix Design," Asphalt Institute Superpave™ Series No.2 (SP-2), Asphalt Institute, P.O. Box 14052, Lexington, KY 40512-4052.

10. HBP Pilot Void Acceptance Projects Completed in 1993-1996, (Interim report by Bud A. Brakey, Colorado Department of Transportation, 4201 East Arkansas Avenue, Denver, CO 80222.) Report No. CDOT-DTD-R-97-8.

11. HBP Pilot Void Acceptance Projects in Region 2 in 1997, (Interim report by Bud A. Brakey, Colorado Department of Transportation, 4201 East Arkansas Avenue, Denver, CO 80222.) Report No. CDOT-DTD-R-98-2.

12. From Corel Quattro Pro 7, 1996 (Spreadsheet Program), @FTEST and @TTEST functions.

13. Colorado Procedure 71-94 For Determining Quality Level (Percent Within Tolerance limits), 1997 Field Materials Manual. Colorado Department of Transportation, 4201 East Arkansas, Denver CO 80222.

Table 1

QC/QA HOT BITUMINOUS PAVEMENT USING CONTRACTOR QC FOR PAY (Includes Voids Accept)

DETAILS AND SUMMARY BY PROJECT AND ELEMENT FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD	SUBAC NUMBR	PRC No	ELE-MENT	BID $ / TON	TONS 1000	TEST "n"	PROCESS ELEMENT DATA & CALCULATI TARG	TOL+,-	MEAN	T-M	SD	QL	PAY FACTOR Vds	QPM2	ACTUAL I/D $	CNT CDE	AGG GRAD	CDOT VERF QL	QC to VER Rqd, >0.005 "F"	"t"
	PG-							Gradation Data is for #8 Sieve													
IM 025 - 302																					
I 25, Hampden South	76-28	11755	1	AC%	$42.00	0.8	2	4.90	0.30	4.91	0.01				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	1	Dens%	$42.00	0.8	1	94.00	2.00	93.20	-0.80				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	1	Grad	$42.00	0.8	2	45.00	5.00	44.00	-1.00				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	1	Voids	$42.00	0.8	2	4.00	1.20	2.30	-1.70			1.000	1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	1	VMA	$42.00	0.8	2	14.50	1.20	13.45	-1.05			1.000	1.000	$0	K1	S(F)			
For information only	76-28	11755	1	VFA	$42.00	0.8	2	70.00	7.00	82.90	12.90						K1	S(F)			
I 25, Hampden South	76-28	11755	2	AC%	$42.00	26.9	59	4.80	0.30	4.76	-0.04	0.12	98.2		1.055	$18,612	K1	S(F)	98.6	0.863	0.232
I 25, Hampden South	76-28	11755	2	Dens%	$42.00	26.9	61	94.00	2.00	92.70	-1.31	0.50	91.7		1.017	$9,160	K1	S(F)	73.2	0.064	0.018
I 25, Hampden South	76-28	11755	2	Grad	$42.00	26.9	32	45.00	5.00	45.40	0.40	2.00	93.9		1.038	$8,498	K1	S(F)	100.0	0.116	0.817
I 25, Hampden South	76-28	11755	2	Voids	$42.00	26.9	33	4.00	1.20	3.96	-0.04	1.01	76.5	1.000	0.913	$0	K1	S(F)	95.2	0.166	0.679
I 25, Hampden South	76-28	11755	2	VMA	$42.00	26.9	33	14.50	1.20	14.55	0.05	0.52	98.2	1.017	1.055	$9,707	K1	S(F)	100.0	0.323	0.159
For information only	76-28	11755	2	VFA	$42.00	26.9	33	70.00	7.00	73.23	3.23	4.90	76.6				K1	S(F)	86.7	OK	OK
PROJECT TOTALS & AVERAGES	QPM 2			ITEM	$42.00	27.7							94.1		1.032	$36,270			86.2		
PROJECT TOTALS & AVERAGES	Vds Acp			ITEM	$42.00	27.7							87.3	1.009	0.984	$9,707			97.6		
																$45,977					
NH 0021-022																					
Colorado Bvd	64-22	11600	1	AC%	$36.00	2.1	5	5.00	0.30	5.23	0.23	0.20	62.8		0.919	($1,878)	K1	S(F)	78.5		
Colorado Bvd	64-22	11600	1	Dens%	$36.00	2.1	4	94.00	2.00	93.75	-0.25	0.88	100.0		1.030	$1,159	K1	S(F)	NA		
Colorado Bvd	64-22	11600	1	Grad	$36.00	2.1	5	45.00	5.00	43.60	-1.40	3.80	62.9		0.920	($1,243)	K1	S(F)	NA		
Colorado Bvd	64-22	11600	1	Voids	$36.00	2.1	5	4.00	1.20	1.58	-2.42	0.36	0.0	1.000	0.500	$0	K1	S(F)	0.0		
Colorado Bvd	64-22	11600	1	VMA	$36.00	2.1	5	15.50	1.20	12.80	-2.70	0.37	0.0	1.000	0.500	$0	K1	S(F)	67.4		
For information only	64-22	11600	1	VFA	$36.00	2.1	5	70.00	7.00	88.10	18.10	5.03	6.8				K1	S(F)	0.0		
Colorado Bvd	64-22	11600	2	AC%	$36.00	0.9	1	5.00	0.30	4.88	-0.12				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	2	Dens%	$36.00	0.9	2	94.00	2.00	95.30	1.30				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	2	Grad	$36.00	0.9	1	37.00	5.00	42.00	5.00				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	2	Voids	$36.00	0.9	1	4.00	1.20	1.70	-2.30			1.000	0.500	$0	K1	S(F)			
Colorado Bvd	64-22	11600	2	VMA	$36.00	0.9	1	15.50	1.20	11.80	-3.70			1.000	0.500	$0	K1	S(F)			
For information only	64-22	11600	2	VFA	$36.00	0.9	1	70.00	7.00	85.60	15.60						K1	S(F)			
Colorado Bvd	64-22	11600	3	AC%	$36.00	24.5	49	4.80	0.30	4.80	0.00	0.18	90.8		1.010	$2,549	K1	S(F)	75.6	0.071	0.338
Colorado Bvd	64-22	11600	3	Dens%	$36.00	24.5	49	94.00	2.00	94.35	0.34	0.70	99.3		1.055	$24,232	K1	S(F)	98.7	0.315	0.756
Colorado Bvd	64-22	11600	3	Grad	$36.00	24.5	27	45.00	5.00	45.10	0.10	2.60	91.5		1.022	$3,833	K1	S(F)	NA	OK	OK
Colorado Bvd	64-22	11600	3	Voids	$36.00	24.5	49	4.00	1.20	4.50	0.50	0.70	82.8	1.000	0.948	$0	K1	S(F)	96.6	0.983	0.736
Colorado Bvd	64-22	11600	3	VMA	$36.00	24.5	49	14.50	1.20	14.90	0.40	0.33	99.5	1.019	1.055	$8,498	K1	S(F)	100.0	0.281	0.255
For information only	64-22	11600	3	VFA	$36.00	24.5	49	70.00	7.00	69.80	-0.20	4.31	90.3				K1	S(F)	86.9	OK	OK
PROJECT TOTALS & AVERAGES	QPM 2			ITEM	$36.00	27.5							94.1		1.031	$28,653			90.0		
PROJECT TOTALS & AVERAGES	Vds Acp			ITEM	$36.00	27.5							81.2	1.008	0.946	$8,498			91.1		
																$37,150					
TOTALS & AVERAGES (2 Projects) Regular Elements					$39.01	55.2							94.1		1.032	$64,923			88.1		
TOTALS & AVERAGES (2 Projects) Voids & VMA					$39.01	55.2							84.3	*1.00887	0.966	$18,205			94.5		
													GRAND TOTAL			$83,127					

* Would have been 0.999, except special provision did not allow disincentive for volumetric properties.

Table 1

QC/QA HOT BITUMINOUS PAVEMENT USING CONTRACTOR QC FOR PAY (Includes Voids Accept)

DETAILS AND SUMMARY BY PROJECT AND ELEMENT FOR 1997 PILOT PROJECTS

PROJECT LOCATION	AC GRAD PG-	SUBAC NUMBR	PRC No	ELE-MENT	BID $ / TON	TONS 1000	TEST "n"	PROCESS ELEMENT DATA & CALCULATI TARG	TOL+,-	MEAN	T-M	SD	QL	PAY FACTOR Vds	QPM2	ACTUAL I/D $	CNT CDE	AGG GRAD	CDOT VERF QL	QC to VER Rqd, >0.005 "F"	"t"
								Gradation Data is for #8 Sieve													
PROJECT DATA SORTED AND SUMMARIZED BY ELEMENT																					
I 25, Hampden South	76-28	11755	1	AC%	$42.00	0.8	2	4.90	0.30	4.91	0.01				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	2	AC%	$42.00	26.9	59	4.80	0.30	4.76	-0.04	0.12	98.2		1.055	$18,612	K1	S(F)	98.6	0.863	0.232
Colorado Bvd	64-22	11600	1	AC%	$36.00	2.1	5	5.00	0.30	5.23	0.23	0.20	62.8		0.919	($1,878)	K1	S(F)	78.5		
Colorado Bvd	64-22	11600	2	AC%	$36.00	0.9	1	5.00	0.30	4.88	-0.12				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	3	AC%	$36.00	24.5	49	4.80	0.30	4.80	0.00	0.18	90.8		1.010	$2,549	K1	S(F)	75.6	0.071	0.338
QC for Pay Weighted Averages & Totals for AC%						55.2	116	4.81	0.30	4.80	-0.01	0.15	93.4		1.028	$19,283			87.2		
I 25, Hampden South	76-28	11755	1	Dens%	$42.00	0.8	1	94.00	2.00	93.20	-0.80				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	2	Dens%	$42.00	26.9	61	94.00	2.00	92.70	-1.31	0.50	91.7		1.017	$9,160	K1	S(F)	73.2	0.064	0.018
Colorado Bvd	64-22	11600	1	Dens%	$36.00	2.1	4	94.00	2.00	93.75	-0.25	0.88	100.0		1.030	$1,159	K1	S(F)	NA		
Colorado Bvd	64-22	11600	2	Dens%	$36.00	0.9	2	94.00	2.00	95.30	1.30				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	3	Dens%	$36.00	24.5	49	94.00	2.00	94.35	0.34	0.70	99.3		1.055	$24,232	K1	S(F)	98.7	0.315	0.756
QC for Pay Weighted Averages & Totals for Density%						55.2	117	94.00	2.00	93.52	-0.48	0.61	95.5		1.034	$34,551			85.4		
I 25, Hampden South	76-28	11755	1	Grad	$42.00	0.8	2	45.00	5.00	44.00	-1.00				1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	2	Grad	$42.00	26.9	32	45.00	5.00	45.40	0.40	2.00	93.9		1.038	$8,498	K1	S(F)	100.0	0.116	0.817
Colorado Bvd	64-22	11600	1	Grad	$36.00	2.1	5	45.00	5.00	43.60	-1.40	3.80	62.9		0.920	($1,243)	K1	S(F)	NA		
Colorado Bvd	64-22	11600	2	Grad	$36.00	0.9	1	37.00	5.00	42.00	5.00				1.000	$0	K1	S(F)			
Colorado Bvd	64-22	11600	3	Grad	$36.00	24.5	27	45.00	5.00	45.10	0.10	2.60	91.5		1.022	$3,833	K1	S(F)	NA	OK	OK
QC for Pay Weighted Averages & Totals for Gradation						55.2	67	44.87	5.00	45.12	0.25	2.35	91.5		1.025	$11,088			100.0		
I 25, Hampden South	76-28	11755	1	VMA	$42.00	0.8	2	14.50	1.20	13.45	-1.05			1.000	1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	2	VMA	$42.00	26.9	33	14.50	1.20	14.55	0.05	0.52	98.2	1.017	1.055	$9,707	K1	S(F)	100.0	0.323	0.159
Colorado Bvd	64-22	11600	1	VMA	$36.00	2.1	5	15.50	1.20	12.80	-2.70	0.37	0.0	1.000	0.500	$0	K1	S(F)	67.4		
Colorado Bvd	64-22	11600	2	VMA	$36.00	0.9	1	15.50	1.20	11.80	-3.70			1.000	0.500	$0	K1	S(F)			
Colorado Bvd	64-22	11600	3	VMA	$36.00	24.5	49	14.50	1.20	14.90	0.40	0.33	99.5	1.019	1.055	$8,498	K1	S(F)	100.0	0.281	0.255
QC for Pay Weighted Averages & Totals for Void in Mineral Agg						55.2	90	14.55	1.20	14.58	0.02	0.43	94.8	1.017	1.024	$18,205			98.1		
I 25, Hampden South	76-28	11755	1	Voids	$42.00	0.8	2	4.00	1.20	2.30	-1.70			1.000	1.000	$0	K1	S(F)			
I 25, Hampden South	76-28	11755	2	Voids	$42.00	26.9	33	4.00	1.20	3.96	-0.04	1.01	76.5	1.000	0.913	$0	K1	S(F)	95.2	0.166	0.679
Colorado Bvd	64-22	11600	1	Voids	$36.00	2.1	5	4.00	1.20	1.58	-2.42	0.36	0.0	1.000	0.500	$0	K1	S(F)	0.0		
Colorado Bvd	64-22	11600	2	Voids	$36.00	0.9	1	4.00	1.20	1.70	-2.30			1.000	0.500	$0	K1	S(F)			
Colorado Bvd	64-22	11600	3	Voids	$36.00	24.5	49	4.00	1.20	4.50	0.50	0.70	82.8	1.000	0.948	$0	K1	S(F)	96.6	0.983	0.736
QC for Pay Weighted Averages & Totals for Air Void %						55.2	90	4.00	1.20	4.05	0.05	0.84	76.4	1.000	0.907	$0			90.5		
VFA not specified, for info only		11755	1	VFA	$42.00	0.8	2	70.00	7.00	82.90	12.90				0.814		K1	S(F)			
VFA not specified, for info only		11755	2	VFA	$42.00	26.9	33	70.00	7.00	73.23	3.23	4.90	76.6		0.914		K1	S(F)	86.7	OK	OK
VFA not specified, for info only		11600	1	VFA	$36.00	2.1	5	70.00	7.00	88.10	18.10	5.03	0.0		0.500		K1	S(F)	0.0		
VFA not specified, for info only		11600	2	VFA	$36.00	0.9	1	70.00	7.00	85.60	15.60				0.690		K1	S(F)			
VFA not specified, for info only		11600	3	VFA	$36.00	24.5	49	70.00	7.00	69.80	-0.20	4.31	90.3		1.006		K1	S(F)	86.9	OK	OK
QC for Pay Weighted Averages & Totals for % Voids Filled/Asphalt						55.2	90	70.00	7.00	72.62	2.62	4.63	79.8		0.934				81.8		
				AC%			116	4.81	0.30	4.80	-0.01	0.15	93.4		1.028	$19,283					
				Dens%			117	94.00	2.00	93.52	-0.48	0.61	95.5		1.034	$34,551					
				Grad			67	44.87	5.00	45.12	0.25	2.35	91.5		1.025	$11,088					
				VMA			90	14.55	1.20	14.58	0.02	0.43	94.8	1.017	1.024	$18,205					
				Voids			90	4.00	1.20	4.05	0.05	0.84	76.3	1.000	0.907	$0					
				VFA (for Info Only)			90	70.00	7.00	72.62	2.62	4.63	79.8		0.934						
QC for Pay : AC%, Density & Gradation					**$39.01**	**55.2**							**94.1**		**1.032**	**$64,923**					
QC for Pay: VMA and AV													**85.6**	**1.0089**		**$18,205**					
If by Proposed: 1998 VA Elements: Density, AC%, Voids & VMA													**89.4**		**0.993**	**($15,070)**					
1997 QPM 2 (Regular QC/QA)					**$31.26**	**378.9**							**91.0**		**1.018**	**$65,710**					
1997 Voids Acceptance Projects in Region 2					**$31.83**	**273.8**							**91.4**	**1.021**	**1.008**	**$201,468**	By proposed 1998 VA spec, $69,720.				

Table 2
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

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: IM0252-302 Location: I 25, Hampden - South

Subaccount 11755 Begin Date: 8/3/97

In-Place Density

Enter Data In Yellow Blocks Only

Target 94.0

Note: F-test compares differences in SD's, t-test differences in means.

Contractor QC		CONTR. COM	Contract Verif	CDOT Verif		Probabilities F & t-test	Probability, Cumulative F & t-test	Probabilities F & t-test
Mean	92.75	92.56	92.40	92.35	Warnin	0.05	0.05	0.05
SD	0.35	0.49	0.54	0.56	Alert	0.01	0.005	0.005
"n"	28	66	38	32				
QL	98.76	87.09	77.06	73.22				

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1.0283					For Action on Verification			For Info. on Verification			Accumultive (For Final)		
Strata	Contractor's Independent R			Split Verif. Tests		Running Sets of 5 Sample			Cumulative Verification			Contractor QC vs Verif		
No.	QC Results			Contr.	CDOT	F-test	t-test	Status	F-test	T-Test	Status	F-test	T-Test	Status
1				92.4	92.4									
2				91.4	91.1									
3				92.0	91.9	0.741	0.270	OK	0.741	0.270	OK			
4				91.9	92.6	0.446	0.753	OK	0.446	0.753	OK			
5				92.7	92.1	0.771	0.795	OK	0.771	0.795	OK			
6			93.1	92.4	92.4	0.771	0.795	OK	0.739	0.788	OK			
7			92.9	92.7	92.1	0.564	0.643	OK	0.920	0.475	OK			
8			92.9	92.4	92.2	0.445	0.591	OK	0.928	0.379	OK	0.130	0.023	Warn
9			93.5	93.2	92.6	0.445	0.034	Warn	0.724	0.211	OK	0.338	0.022	Warn
10			92.5	93.2	92.7	0.398	0.034	Warn	0.587	0.120	OK	0.412	0.071	OK
11			92.4	92.0	92.0	0.345	0.034	Warn	0.528	0.120	OK	0.506	0.074	OK
12			92.2	92.0	92.3	0.178	0.290	OK	0.467	0.196	OK	0.687	0.095	OK
13			92.6	92.0	91.7	0.397	0.255	OK	0.522	0.138	OK	0.576	0.064	OK
14			92.7	92.2	92.4	0.566	0.710	OK	0.525	0.185	OK	0.492	0.040	Warn
15			92.6	92.0	92.2	0.050	0.495	Warn	0.476	0.240	OK	0.412	0.025	Warn
16			92.7	91.8	92.1	0.238	0.280	OK	0.390	0.340	OK	0.302	0.012	Warn
17			92.3	92.3	92.4	0.688	0.295	OK	0.396	0.374	OK	0.357	0.014	Warn
18			92.7	92.7	92.9	0.858	0.003	Alert	0.550	0.451	OK	0.275	0.014	Warn
19			92.4	92.4	92.0	0.976	0.554	OK	0.558	0.327	OK	0.279	0.015	Warn
20			92.7	93.1	93.6	0.560	0.404	OK	0.896	0.523	OK	0.151	0.025	Alert
21			92.6	91.8	91.5	0.339	0.910	OK	0.795	0.421	OK	0.104	0.014	Warn
22			93.0	92.4	92.7	0.324	0.749	OK	0.730	0.534	OK	0.111	0.008	Warn
23			93.2	93.6	93.3	0.672	0.838	OK	0.936	0.434	OK	0.049	0.020	Warn
24			93.3	93.0	93.2	0.744	0.648	OK	0.838	0.506	OK	0.064	0.018	Warn

Figure SS-1

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: IM0252-302 Location: I 25, Hampden - South

Subaccount 11755 Begin Date: 8/3/97

ASPHALT CONTENT

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Target 4.80

Note: F-test compares differences in SD's, t-test differences in means.

Contractor QC		CONTR. COM	Contracto Verif	CDOT Verif		5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Mean	4.78	4.77	4.73	4.86	Warning	0.05	0.05	0.05
SD	0.12	0.12	0.12	0.14	Alert	0.01	0.01	0.005
"n"	49	61	12	12				
QL	98.68	98.41	97.78	96.62				

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
										For Action on Verification			For Info. on Verification			Accumultive (For Final)		
Strata	Contractor's Independent Random							Verification		Running Sets of 5 Samples			Cumulative Verification			Contractor QC vs Verif		
No.	Quality Control Test Results							Contracto	CDOT	F-test	t-test	Status	F-test	T-Test	Status	F-test	T-Test	Status
1								4.75	4.61									
2								4.79	4.88									
3								4.74	4.84	0.064	0.851	OK	0.064	0.851	OK			
4								4.41	4.82	0.552	0.383	OK	0.552	0.383	OK			
5								4.77	4.71	0.498	0.443	OK	0.498	0.443	OK			
6	4.65	4.84	4.59	4.75	4.63	4.75	4.58	4.58	4.79	0.100	0.126	OK	0.388	0.259	OK	0.327	0.876	OK
7	4.82	4.86	4.70	4.60	4.77	4.65	4.80	4.81	4.79	0.038	0.206	Warn	0.272	0.272	OK	0.211	0.701	OK
8	4.91	4.80	4.84	4.84	4.88	4.60	4.56	4.82	5.03	0.461	0.156	OK	0.705	0.153	OK	0.400	0.617	OK
9	4.84	4.57	4.99	4.78	4.83	4.99	4.78	4.88	5.06	0.546	0.155	OK	0.958	0.087	OK	0.540	0.559	OK
10	4.83	4.84	4.85	4.95	4.86	4.92	5.05	4.79	5.07	0.660	0.028	Warn	0.764	0.041	Warn	0.750	0.280	OK
11	4.86	4.90	4.89	4.86	4.89	4.78	4.69	4.71	4.81	0.140	0.043	Warn	0.742	0.027	Warn	0.743	0.145	OK
12	4.74	4.72	4.60	4.71	4.77	4.80	4.57	4.75	4.89	0.291	0.004	Alert	0.725	0.015	Warn	0.863	0.232	OK

Figure SS-2

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: IM0252-302 Location: I 25, Hampden - South

Subaccount: 11755 Begin Date: 8/3/97

PERCENT AIR VOIDS

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Note: F-test compares differences in SD's, t-test differences in means.

Target 4.00

	Contractor QC	CONTR. COMB	Contractor Verif	CDOT Verif
Mean	4.01	3.84	3.56	4.02
SD	1.15	1.21	1.30	0.65
"n"	21	34	13	12
QL	70.23	67.38	61.72	95.18

	5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.01	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strata	Contractor's Independent Random			Verification		For Action on Verification Running Sets of 5 Samples			For Info. on Verification Cumulative Verification			Accumultive (For Final) Contractor QC vs Verif		
No.	QC Test Results			Contr	CDOT	F-test	t-test	Status F & t	F-test	T-Test	Status F & t	F-test	T-Test	Status F & t
1				3.40	4.78									
2				3.40	4.33									
3				4.40	4.48	0.272	0.172	OK	0.272	0.172	OK			
4				4.00	4.34	0.197	0.102	OK	0.197	0.102	OK			
5				4.00	3.87	0.605	0.136	OK	0.605	0.136	OK			
6	4.70	4.90	5.80	4.80	4.18	0.214	0.524	OK	0.302	0.246	OK	0.661	0.016	Warn
7	4.30	5.10	4.70	4.80	4.37	0.445	0.491	OK	0.118	0.373	OK	0.873	0.017	Warn
8	3.60	2.80	5.20	4.30	4.55	0.530	0.656	OK	0.104	0.303	OK	0.161	0.229	OK
9	4.50	5.90	4.40	4.30	3.58	0.664	0.152	OK	0.416	0.546	OK	0.116	0.119	OK
10	4.60	3.60	3.20	3.90	3.90	0.827	0.200	OK	0.460	0.543	OK	0.058	0.231	OK
11	4.30	3.10	2.20	3.20	3.39	0.735	0.490	OK	0.547	0.482	OK	0.037	0.464	Warn
12	3.20	2.00	2.20	2.00	2.41	0.685	0.902	OK	0.590	0.373	OK	0.166	0.679	OK

Figure SS-3

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: IM0252-302 Location: I 25, Hampden - South

Subaccount: 11755 Begin Date: 8/3/97

PERCENT VOIDS in MINERAL AGGREGATE (VMA)

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Note: F-test compares differences in SD's, t-test differences in means.

Target 14.50

	Contractor QC	CONTR. COMB	Contractor Verif	CDOT Verif
Mean	14.64	14.54	14.37	14.45
SD	0.57	0.53	0.42	0.38
"n"	21	33	12	12
QL	96.88	98.12	99.90	100.00

	5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.01	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strata	Contractor's Independent Random			Verification		For Action on Verification Running Sets of 5 Samples			For Info. on Verification Cumulative Verification			Accumultive (For Final) Contractor QC vs Verif		
No.	QC Test Results			Contr	CDOT	F-test	t-test	Status F & t	F-test	T-Test	Status F & t	F-test	T-Test	Status F & t
1				14.10	14.70									
2				14.00	14.50									
3				14.30	14.40	1.000	0.120	OK	1.000	0.120	OK			
4				13.90	14.40	0.764	0.031	Warn	0.764	0.031	Warn			
5				14.30	14.00	0.509	0.172	OK	0.509	0.172	OK			
6	14.40	15.10	15.20	14.50	14.10	0.819	0.697	OK	0.751	0.393	OK	0.196	0.012	Warn
7	14.70	14.70	14.50	14.90	14.70	0.614	0.732	OK	0.600	0.501	OK	0.922	0.024	Warn
8	14.40	14.20	15.60	15.10	15.00	0.796	0.561	OK	0.510	0.554	OK	0.870	0.107	OK
9	15.00	15.40	15.30	14.70	14.80	0.528	0.105	OK	0.523	0.494	OK	0.802	0.030	Warn
10	15.10	14.70	14.40	14.70	14.80	0.452	0.351	OK	0.529	0.438	OK	0.853	0.029	Warn
11	15.10	14.20	13.80	14.20	14.30	0.631	1.000	OK	0.521	0.387	OK	0.456	0.060	OK
12	14.30	13.60	13.70	13.70	13.70	0.960	0.374	OK	0.731	0.384	OK	0.323	0.159	OK

Figure SS-4

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: NH 0021-022 Location: Colo Blvd; Miss-MLK Blvd

Subaccount: 11600, Pr 3 Begin Date: 8/25/97

In-Place Density

Enter Data In Yellow Blocks Only

Target 94.00

Note: F-test compares differences in SD's, t-test differences in means.

	Contractor QC		CONTR. COMB	Contractor Verif	CDOT Verif
Mean	94.40		94.40	94.36	94.27
SD	0.61		0.69	0.69	0.78
"n"	22		22	49	54
QL	99.80		99.80	99.27	98.69

	Probabilities F & t-test	Probability, Cumulative F & t-test	Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.005	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1.0283					For Action on Verification			For Info. on Verification			Accumultive (For Final)		
Strata	Contractor's Independent Random			Split Verif.		Running Sets of 5 Samples			Cumulative Verification			Contractor QC vs Verif		
No.	QC Resu	QC Result	QC Result	Contractor	CDOT	F-test	t-test	Status	F-test	T-Test	Status	F-test	T-Test	Status
1				95.8	94.0									
2				95.8	94.7									
3				93.7	93.7	0.304	0.206	OK	0.304	0.206	OK			
4				95.4	95.6	0.786	0.248	OK	0.786	0.248	OK			
5				95.6	92.7	0.703	0.124	OK	0.703	0.124	OK			
6			94.4	94.5	94.6	0.675	0.277	OK	0.749	0.133	OK			
7			95.8	93.8	95.0	0.630	0.705	OK	0.951	0.289	OK			
8			95.6	94.6	93.4	0.369	0.503	OK	0.836	0.181	OK	0.997	0.537	OK
9			95.4	95.4	95.2	0.463	0.434	OK	0.730	0.163	OK	0.693	0.476	OK
10			94.8	94.6	95.8	0.400	0.654	OK	0.488	0.303	OK	0.588	0.497	OK
11			94.5	94.1	95.1	0.474	0.449	OK	0.526	0.439	OK	0.556	0.530	OK
12			94.3	94.2	94.6	0.299	0.611	OK	0.567	0.494	OK	0.603	0.608	OK
13			94.1	94.4	93.9	0.552	0.313	OK	0.530	0.427	OK	0.731	0.756	OK
14			94.6	94.3	95.1	0.028	0.126	Warn	0.505	0.544	OK	0.638	0.725	OK
15			93.9	94.5	94.2	0.036	0.397	Warn	0.486	0.501	OK	0.825	0.925	OK
16			94.0	94.0	94.7	0.117	0.451	OK	0.546	0.607	OK	0.838	0.988	OK
17			94.5	94.5	93.8	0.646	1.000	OK	0.479	0.509	OK	0.788	0.998	OK
18			94.3	93.5	93.8	0.570	0.609	OK	0.621	0.551	OK	0.571	0.883	OK
19			94.1	94.4	93.7	0.942	0.642	OK	0.552	0.460	OK	0.592	0.971	OK
20			93.9	93.4	94.3	0.761	0.784	OK	0.756	0.591	OK	0.487	0.926	OK
21			94.3	94.1	94.3	0.319	1.000	OK	0.777	0.619	OK	0.443	0.905	OK
22			94.4	94.4	93.5	0.596	0.910	OK	0.667	0.501	OK	0.412	0.911	OK
23			94.0	93.5	93.8	0.596	0.910	OK	0.774	0.541	OK	0.336	0.855	OK
24			94.4	92.9	94.2	0.346	0.390	OK	0.883	0.739	OK	0.158	0.643	OK
25			94.0	94.4	92.5	0.842	0.734	OK	0.697	0.508	OK	0.165	0.718	OK
26			93.0	93.4	94.3	0.866	0.924	OK	0.817	0.625	OK	0.362	0.842	OK
27			94.4	93.8	93.1	0.542	0.974	OK	0.705	0.540	OK	0.315	0.756	OK

Figure SS-5

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: NH 0021-022 Location: Colo Blvd; Miss-MLK Blvd

Subaccount: 11600, Pr 3 Begin Date: 8/28/97

ASPHALT CONTENT

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Target 4.80

Note: F-test compares differences in SD's, t-test differences in means.

	Contractor QC		CONTR. COMB	Contracto Verif	CDOT Verif
Mean	4.81		4.80	4.77	4.69
SD	0.16		0.18	0.24	0.23
"n"	38		49	11	11
QL	94.33		90.79	78.50	75.57

	5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.01	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
										For Action on Verification			For Info. on Verification			Accumultive (For Final)		
Strata	Contractor's Independent Random							Verification		Running Sets of 5 Samples			Cumulative Verification			Contractor QC vs Verif		
No.	Quality Control Test Results							Contracto	CDOT	F-test	t-test	Status	F-test	T-Test	Status	F-test	T-Test	Status
1								5.18	4.88									
2								5.23	4.92									
3								4.65	4.65	0.341	0.184	OK	0.341	0.184	OK			
4								4.52	4.24	0.811	0.058	OK	0.811	0.058	OK			
5								4.53	4.44	0.707	0.037	Warn	0.707	0.037	Warn			
6	4.77	4.64	4.53	4.59	4.61	5.02	4.93	4.65	4.65	0.790	0.113	OK	0.635	0.045	Warn	0.209	0.654	OK
7	4.68	4.85	4.84	4.80	4.83	4.77	4.78	4.78	4.55	0.374	0.108	OK	0.613	0.017	Warn	0.019	0.739	Warn
8	4.89	4.80	4.92	4.70	4.92	4.75	4.75	4.68	5.03	0.081	0.678	OK	0.907	0.219	OK	0.004	0.978	Alert
9	4.60	4.64	5.06	5.08	4.57	5.03	5.08	4.91	4.68	0.414	0.727	OK	0.869	0.129	OK	0.059	0.904	OK
10	4.65	4.79	5.03	5.09	4.90	4.86	4.75	4.79	4.61	0.267	0.627	OK	0.868	0.080	OK	0.068	0.735	OK
11	4.90	4.60	4.69					4.58	4.91	0.356	0.956	OK	0.902	0.259	OK	0.071	0.338	OK

Figure SS-6

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: NH 0021-02 Location: Colo Blvd, Miss-MLK Blvd

Subaccount: 11600, Pr 3 Begin Date: 8/28/97

PERCENT AIR VOIDS

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Note: F-test compares differences in SD's, t-test differences in means.

Target 4.00

	Contractor QC	CONTR. COM	Contractor Verif	CDOT Verif
Mean	4.44	4.52	4.63	4.01
SD	0.73	0.70	0.68	0.62
"n"	16	27	11	11
QL	84.12	82.81	79.77	96.55

	5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.01	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
						For Action on Verification			For Info. on Verification			Accumulative (For Final)		
Strata	Contractor's Independent Ran			Verification		Running Sets of 5 Samples			Cumulative Verification			Contractor QC vs Verif		
No.	QC Test Results			Contr	CDOT	F-test	t-test	Status F & t	F-test	T-Test	Status F & t	F-test	T-Test	Status F & t
1				4.40	3.33									
2				4.40	3.46									
3				5.20	4.08	0.859	0.003	Alert	0.859	0.003	Alert			
4				5.90	4.84	0.942	0.000	Alert	0.942	0.000	Alert			
5				5.30	5.13	0.674	0.008	Alert	0.674	0.008	Alert			
6	4.50	5.10	4.30	4.60	4.35	0.865	0.026	Warn	0.697	0.008	Alert	0.709	0.424	OK
7	5.00	4.60	4.70	4.30	4.16	0.549	0.069	OK	0.836	0.008	Alert	0.151	0.543	OK
8	5.60	4.90	4.70	4.00	3.67	0.578	0.084	OK	0.999	0.005	Alert	0.175	0.816	OK
9	5.50	3.70	3.60	3.40	4.31	0.583	0.987	OK	0.542	0.069	OK	0.528	0.811	OK
10	4.10	4.30	2.90	4.50	3.40	0.799	0.601	OK	0.675	0.032	Warn	0.983	0.736	OK
11	3.60			4.90	3.40	0.602	0.359	OK	0.768	0.014	Warn			Alert

Figure SS-7

QC Data Verification Program Version 1.004

PROGRAM FOR COMPARING CONTRACTOR QUALITY CONTROL FOR PAY & CDOT VERIFICATION DATA SETS

PROJECT: NH 0021-022 Location: Colo Blvd, Miss-MLK Blvd

Subaccount: 11600, Pr 3 Begin Date: 8/28/97

PERCENT VOIDS in MINERAL AGGREGATE (VMA)

Enter Data In Yellow Blocks Only

Statistical Data Based on Entries Below

Note: F-test compares differences in SD's, t-test differences in means.

Target 14.50

	Contractor QC	CONTR. COM	Contractor Verif	CDOT Verif
Mean	14.83	14.89	14.98	14.44
SD	0.36	0.33	0.26	0.26
"n"	16	27	11	11
QL	99.59	99.54	100.00	100.00

	5 Test Running Evaluation Probabilities F & t-test	Verification Samples Probability, Cumulative F & t-test	Contractor QC vs Verif Probabilities F & t-test
Warning	0.05	0.05	0.05
Alert	0.01	0.01	0.005

Col 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
						For Action on Verification			For Info. on Verification			Accumulative (For Final)		
Strata	Contractor's Independent Ran			Verification		Running Sets of 5 Samples			Cumulative Verification			Contractor QC vs Verif		
No.	QC Test Results			Contr	CDOT	F-test	t-test	Status F & t	F-test	T-Test	Status F & t	F-test	T-Test	Status F & t
1				15.30	14.40									
2				15.20	14.40									
3				15.40	14.10	0.500	0.023	Warn	0.500	0.023	Warn			
4				15.20	14.90	0.071	0.028	Warn	0.071	0.028	Warn			
5				14.90	14.50	0.423	0.015	Warn	0.423	0.015	Warn			
6	14.60	14.90	14.20	14.70	14.10	0.738	0.018	Warn	0.804	0.005	Alert	0.524	0.032	Warn
7	15.00	14.90	15.00	15.00	14.20	0.653	0.018	Warn	0.746	0.001	Alert	0.560	0.055	OK
8	15.60	14.70	14.90	14.70	14.80	0.346	0.058	OK	0.761	0.004	Alert	0.391	0.269	OK
9	15.50	14.30	14.90	14.70	14.60	0.197	0.092	OK	0.908	0.005	Alert	0.272	0.401	OK
10	14.60	14.90	14.60	14.90	14.30	0.190	0.079	OK	0.891	0.002	Alert	0.281	0.255	OK
11	14.70			14.80	14.50	0.268	0.105	OK	0.947	0.001	Alert			Alert

Figure SS-8

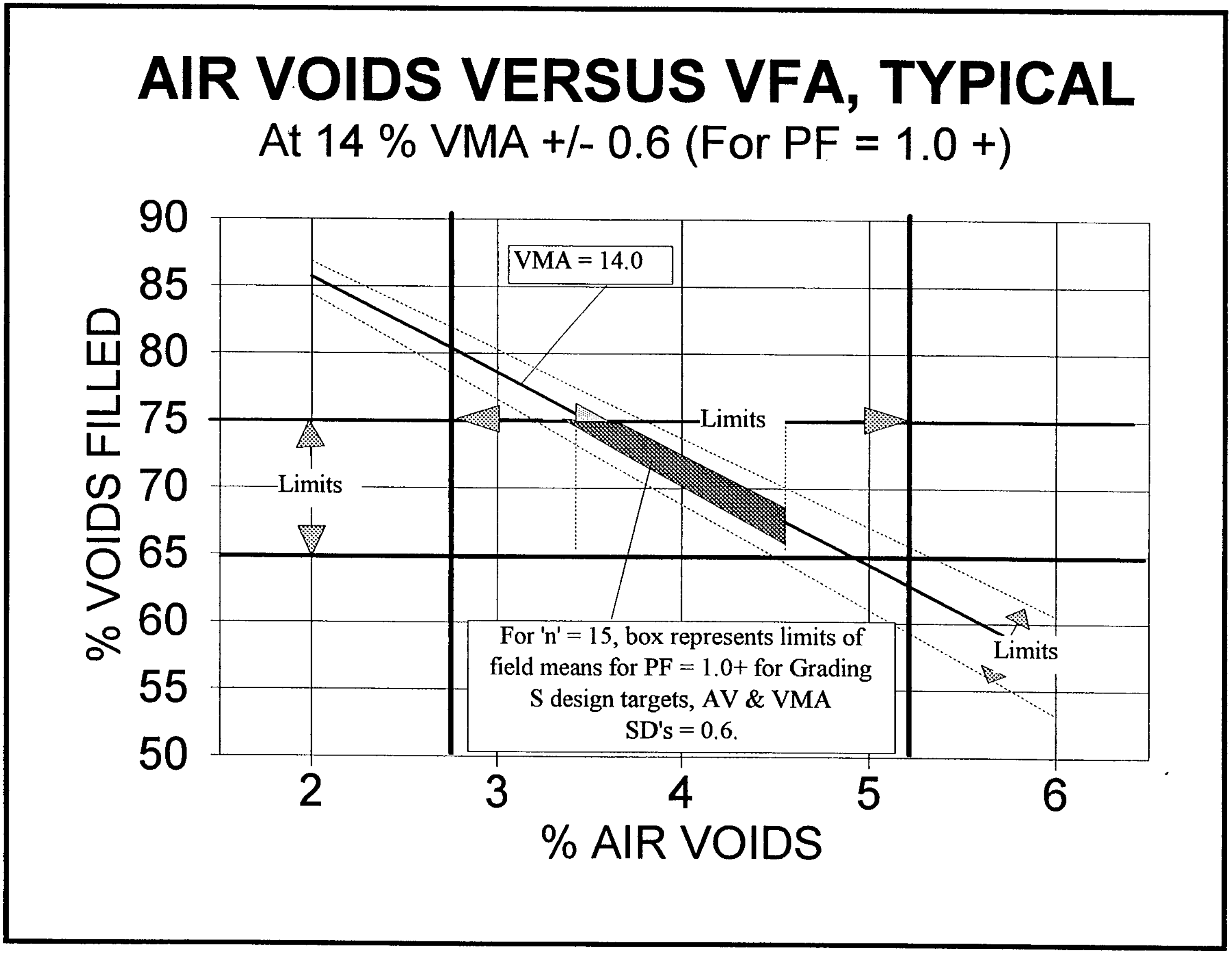

AIR VOIDS VERSUS VFA, TYPICAL
At 14 % VMA +/- 0.6 (For PF = 1.0 +)
VMA = 14.0
Limits
Limits
Limits
For 'n' = 15, box represents limits of field means for PF = 1.0+ for Grading S design targets, AV & VMA SD's = 0.6.
% VOIDS FILLED
90
85
80
75
70
65
60
55
50
2
3
4
5
6
% AIR VOIDS

Figure 1

IN-PLACE ASPHALT DENSITY: I 25, HAMPDEN SOUTH

(Includes Verification Set No 11, a matching pair of tests greater than 2 x V below lower Tolerance limit)

Density Data Summary	Target		Contr QC	Contr Com-bined	Contr Verifi-cation	CDOT Verifi-cation
	94	Mean	92.73	92.49	92.29	92.25
		SD	0.35	0.64	0.75	0.74
		"n"	20	45	25	25

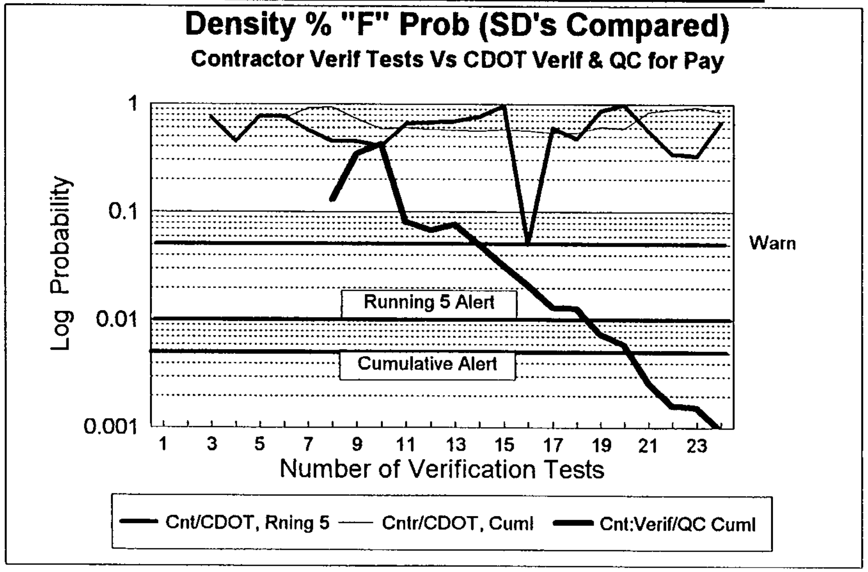


Figure 2

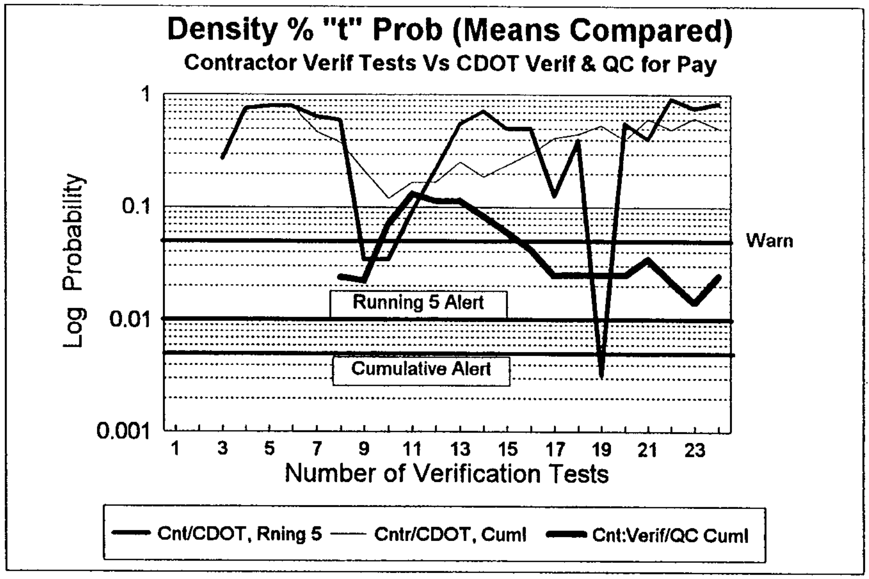


Figure 3

IN-PLACE ASPHALT DENSITY: I 25, HAMPDEN SOUTH

(Excludes Verification Set No 11, a matching pair of tests greater than 2 x V below lower Tolerance limit)

Density Data Summary	Target		Contr QC	Contr Com-bined	Contr Verifi-cation	CDOT Verifi-cation
	94	Mean	92.56	92.40	92.40	92.38
		SD	0.35	0.49	0.54	0.56
		"n"	19	43	24	24

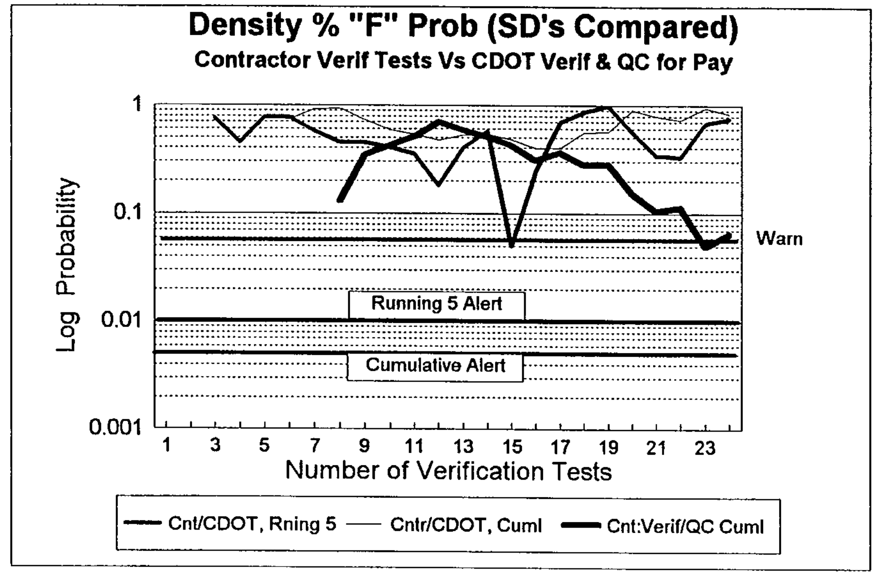


Figure 4

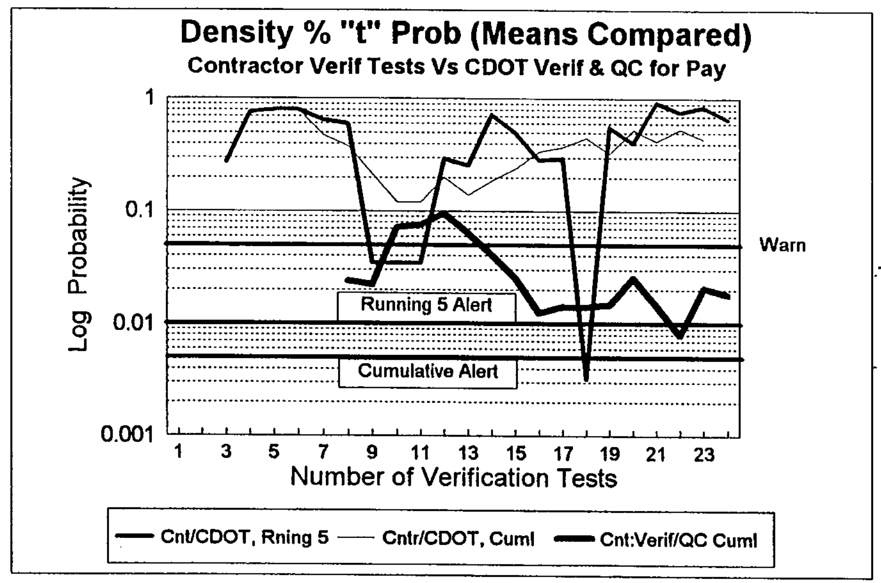


Figure 5

REDUCED VERIFICATION, 1 Ver To 7 QC
IN-PLACE ASPHALT DENSITY: I 25, HAMPDEN SOUTH
(Excludes Verification Set No 11, a matching pair of tests greater than 2 x V below lower Tolerance limit)

Density Data Summary	Target		Contr QC		Contr Com-bined		Contr Verifi-cation		CDOT Verifi-cation	
	94	Mean		92.65		92.56		92.25		92.24
		SD		0.45		0.49		0.53		0.52
		"n"		33		43		10		10

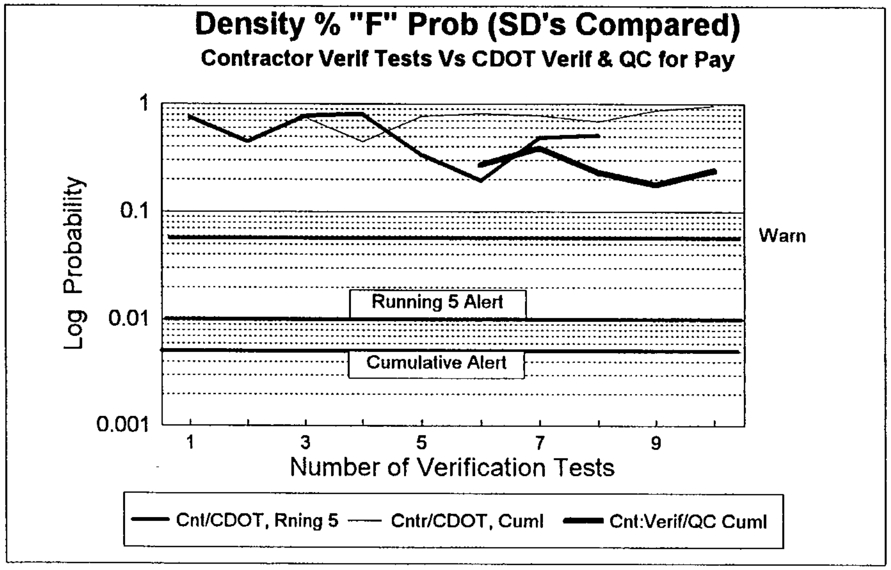


Figure 6

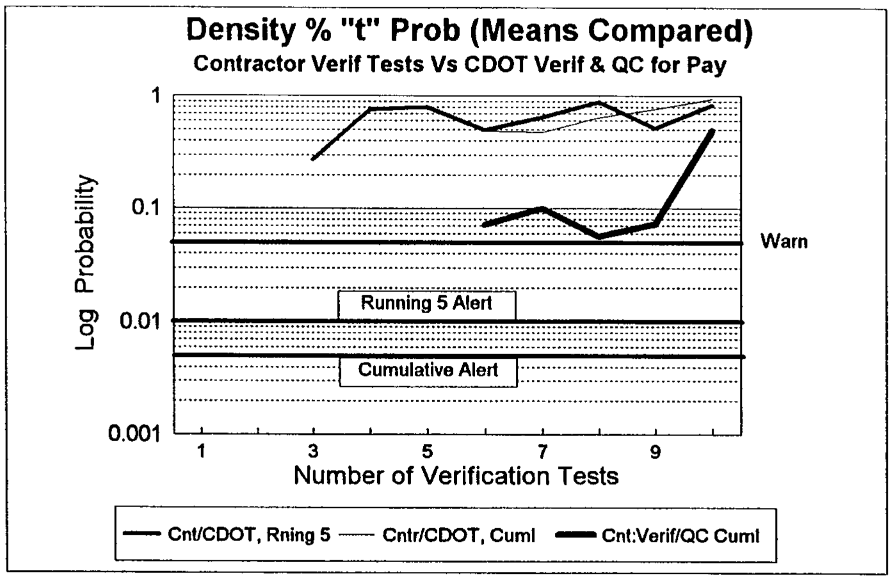


Figure 7

ASPHALT CONTENT: I 25, HAMPDEN SOUTH

Asphalt % Data Summary	Target		Contr QC		Contr Com-bined		Contr Verifi-cation		CDOT Verifi-cation	
	4.8	Mean		4.78		4.77		4.73		4.86
		SD		0.12		0.12		0.12		0.14
		"n"		49		61		12		12

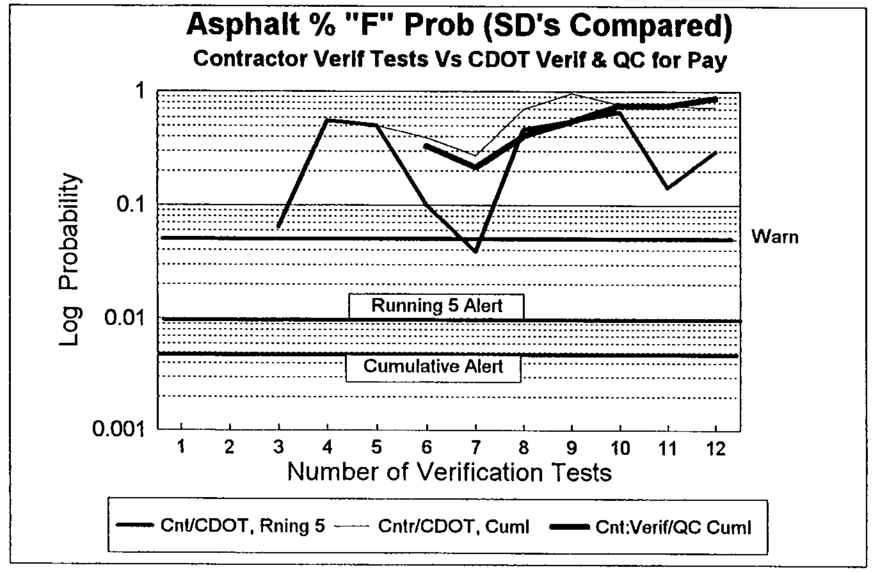


Figure 8

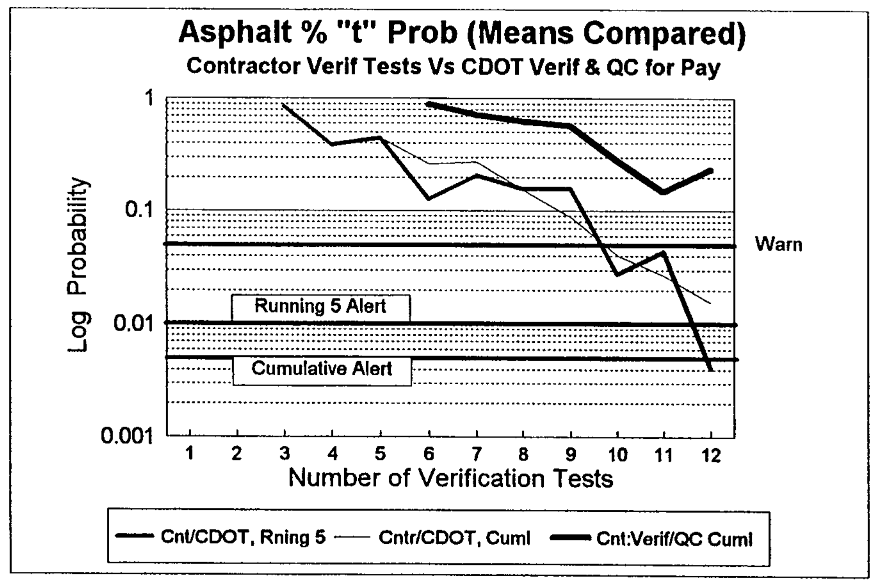


Figure 9

VOIDS MINERAL AGGREGATE: I 25, HAMPDEN SOUTH

Voids Mineral Aggr. Summary	Target									
	Target	Mean	Contr QC	14.84	Contr Com-bined	14.54	Contr Verifi-cation	14.37	CDOT Verifi-cation	14.45
	14.5	SD		0.57		0.53		0.42		0.38
		"n"		21		33		12		12

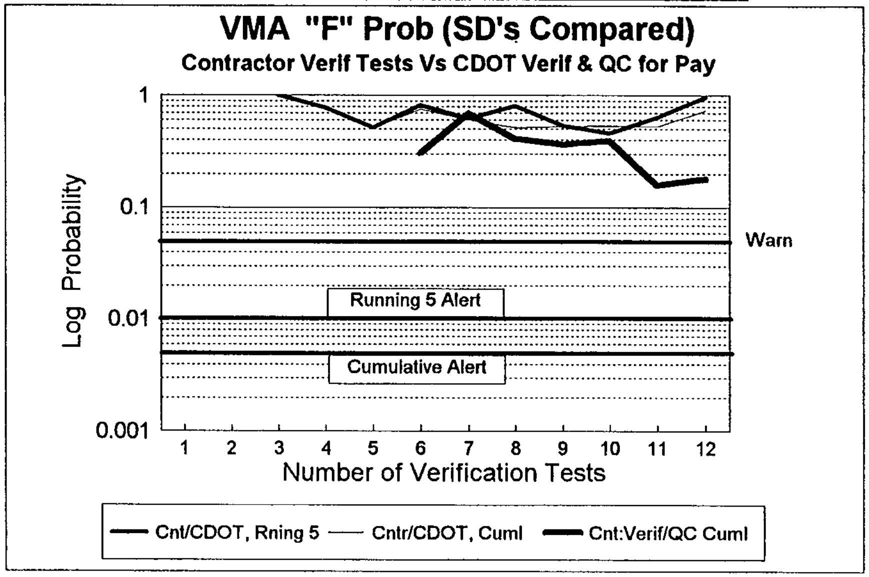


Figure 10

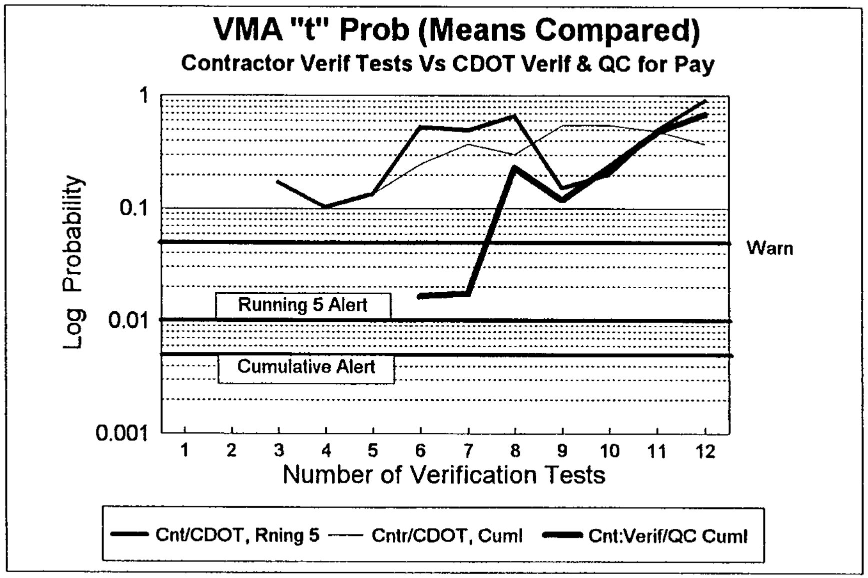


Figure 11

REDUCED VERIFICATION, 1 Ver To 7 QC
VOIDS MINERAL AGGREGATE: I 25, HAMPDEN SOUTH

Voids Mineral Aggr. Summary	Target									
	Target	Mean	Contr QC	14.84	Contr Com-bined	14.54	Contr Verifi-cation	14.28	CDOT Verifi-cation	14.41
	14.5	SD		0.53		0.53		0.45		0.39
		"n"		24		33		9		9

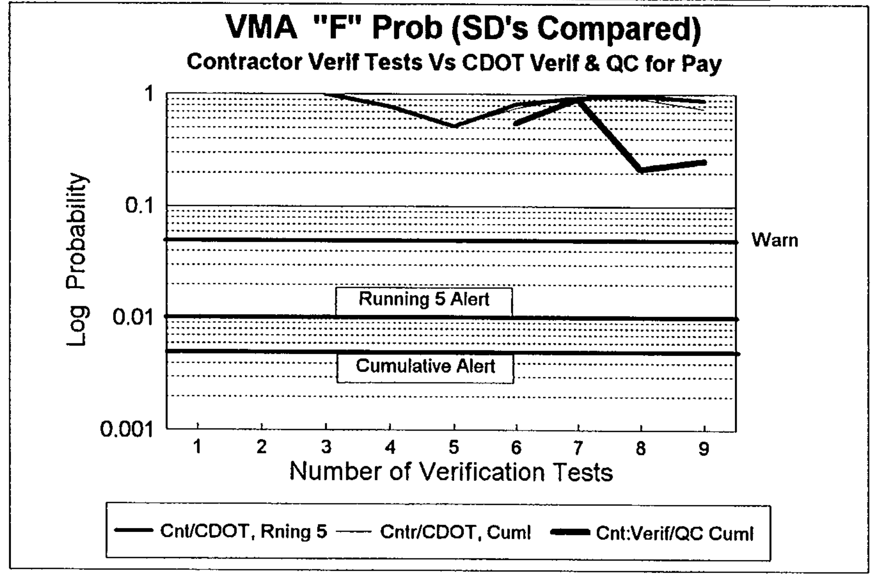


Figure 12

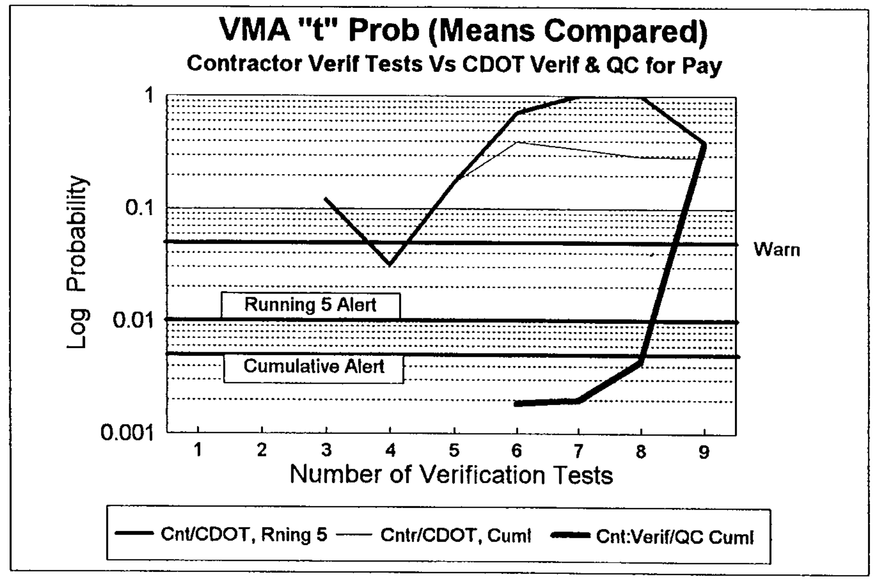


Figure 13

PERCENT AIR VOIDS: I 25, HAMPDEN SOUTH

% Air Voids Summary	Target									
	4.0	Mean	Contr QC	4.01	Contr Com-bined	3.96	Contr Verifi-cation	3.88	CDOT Verifi-cation	4.02
		SD		1.15		1.02		0.77		0.65
		"n"		21		33		12		12

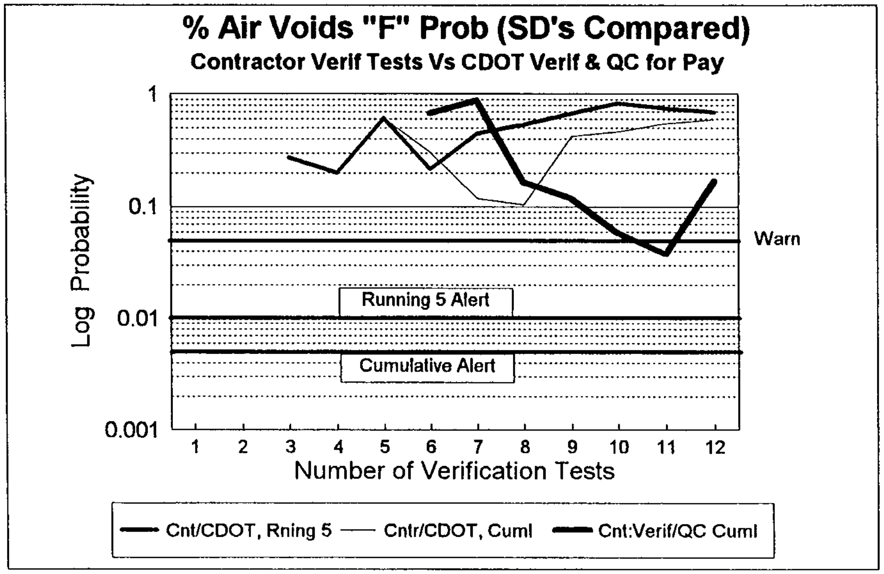


Figure 14

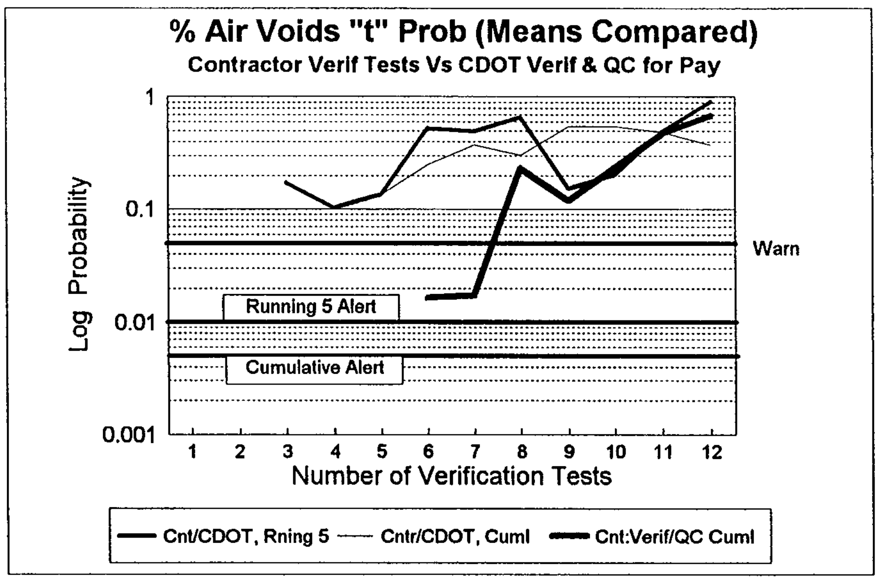


Figure 15

REDUCED VERIFICATION, 1 Ver To 7 QC
PERCENT AIR VOIDS: I 25, HAMPDEN SOUTH

% Air Voids Summary	Target									
	4.0	Mean	Contr QC	4.05	Contr Com-bined	3.96	Contr Verifi-cation	3.70	CDOT Verifi-cation	3.93
		SD		1.09		1.02		0.80		0.72
		"n"		24		33		9		9

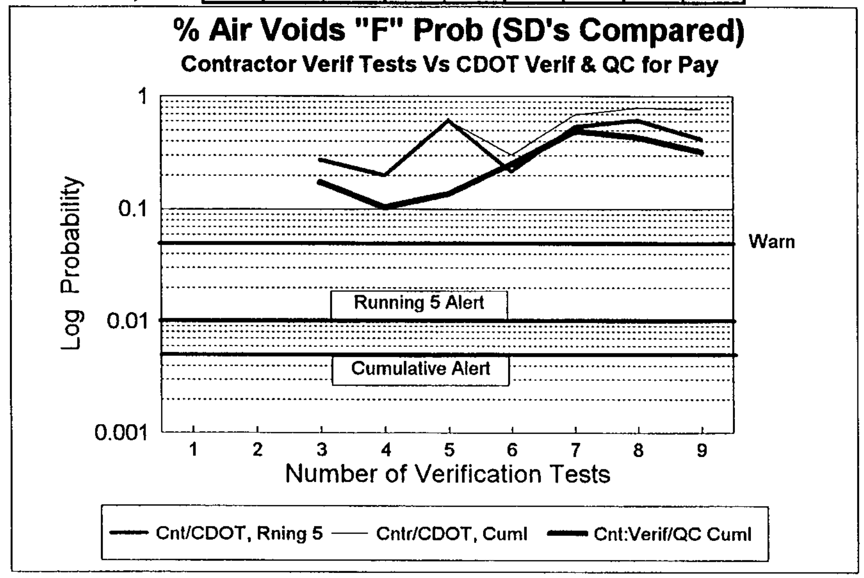


Figure 16

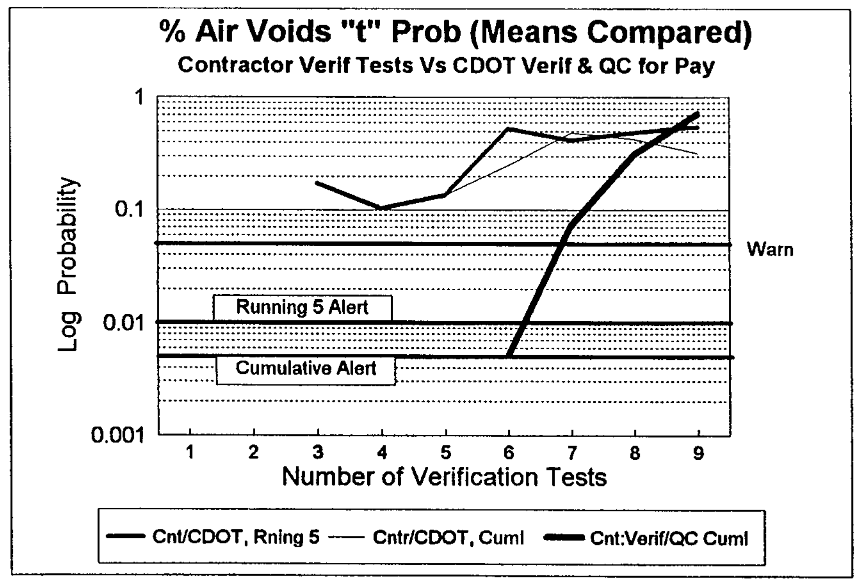


Figure 17

IN-PLACE ASPHALT DENSITY: COLO BLVD, MISS - MLK BLVD

Density Data Summary	Target	Mean	Contr	94.40	Contr	94.36	Contr	94.33	CDOT	94.21
	94	SD	QC	0.61	Com-	0.69	Verifi-	0.75	Verifi-	0.81
		"n"		22	bined	49	cation	27	cation	27

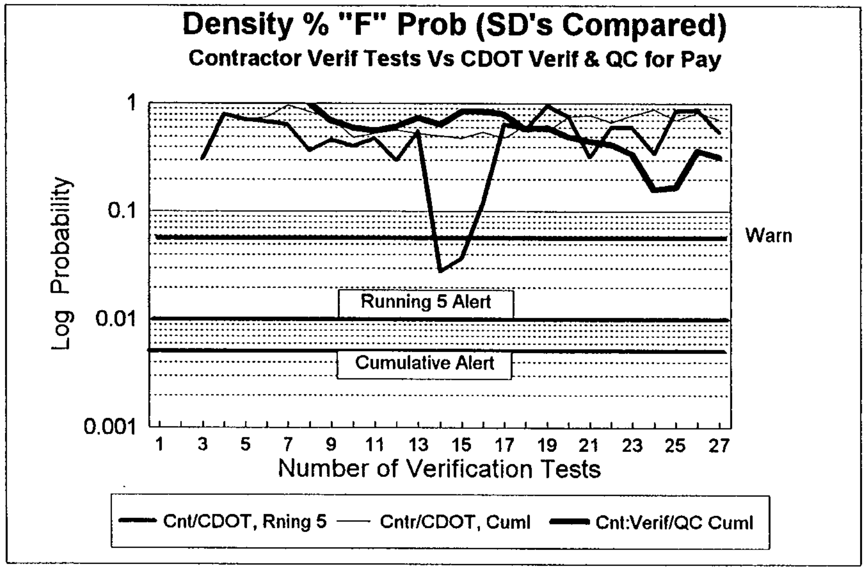


Figure 18

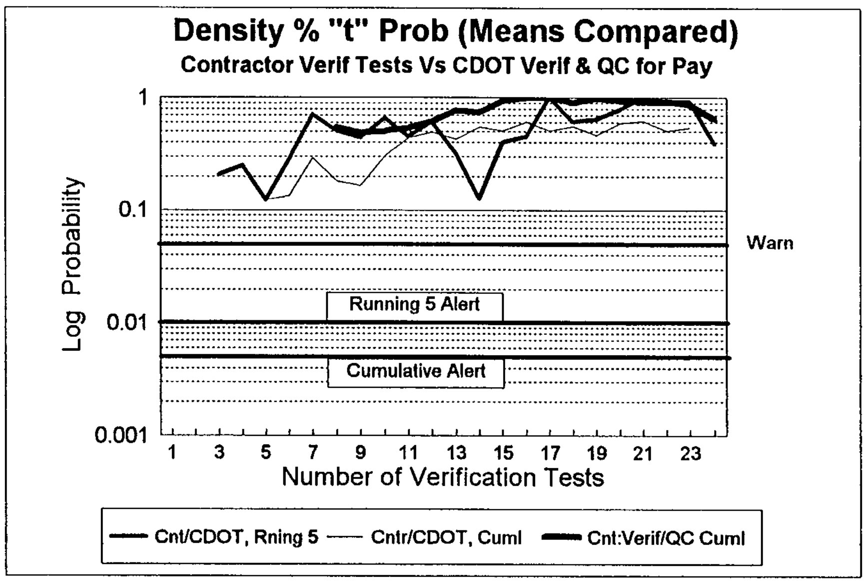


Figure 19

ASPHALT CONTENT: COLO BLVD, MISS - MLK BLVD

Asphalt % Data Summary	Target	Mean	Contr	4.81	Contr	4.80	Contr	4.77	CDOT	4.69
	4.8	SD	QC	0.16	Com-	0.18	Verifi-	0.24	Verifi-	0.23
		"n"		38	bined	49	cation	11	cation	11

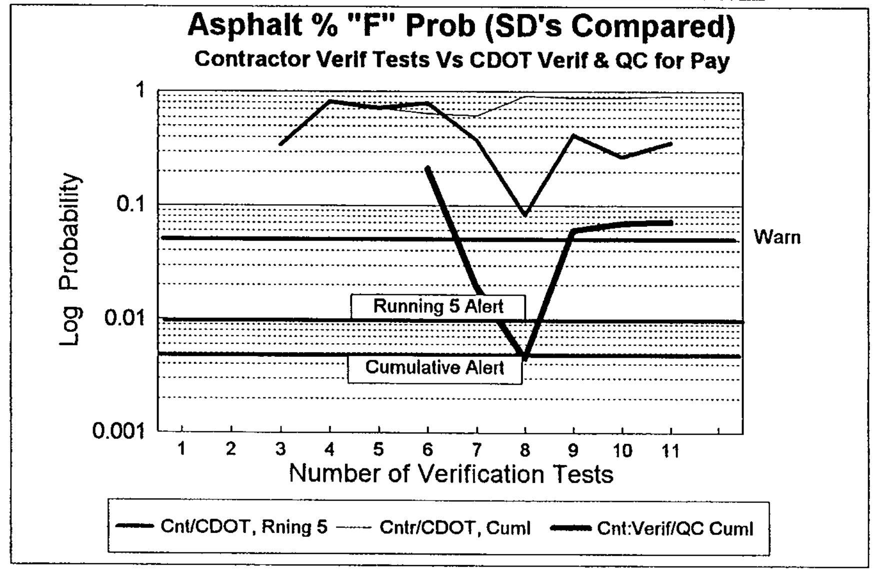


Figure 20

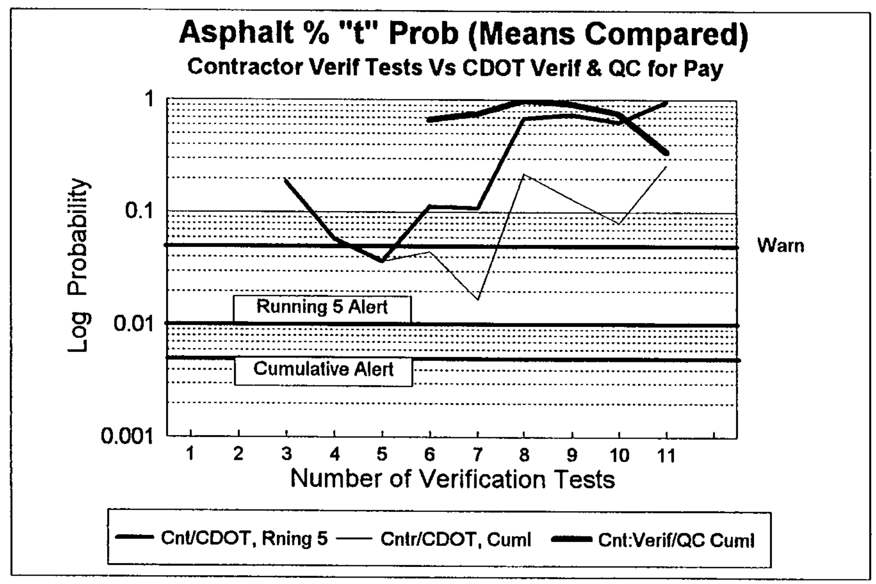


Figure 21

PERCENT AIR VOIDS: COLO BLVD, MISS - MLK BLVD

% Air Voids Summary	Target		Contr QC	Contr Combined	Contr Verification	CDOT Verification
	4.0	Mean	4.44	4.52	4.63	4.01
		SD	0.73	0.68	0.68	0.62
		"n"	16	27	11	11

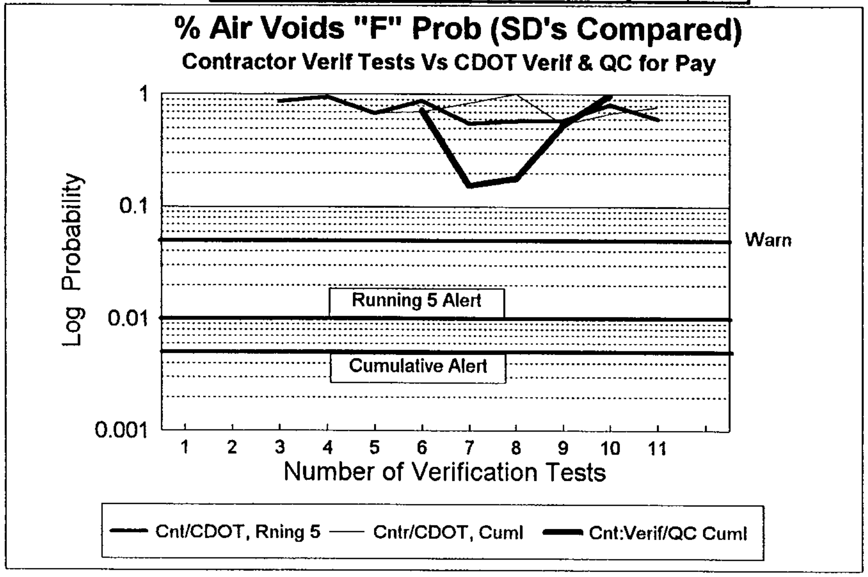


Figure 22

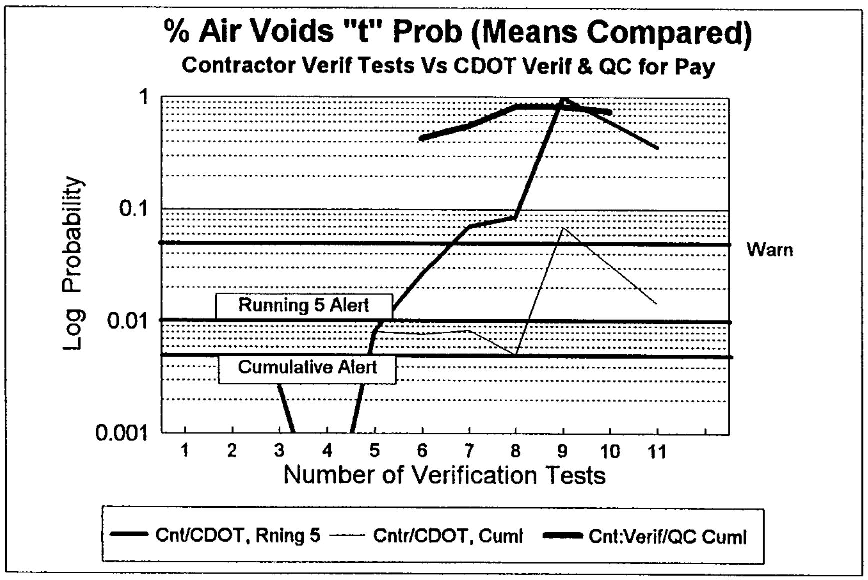
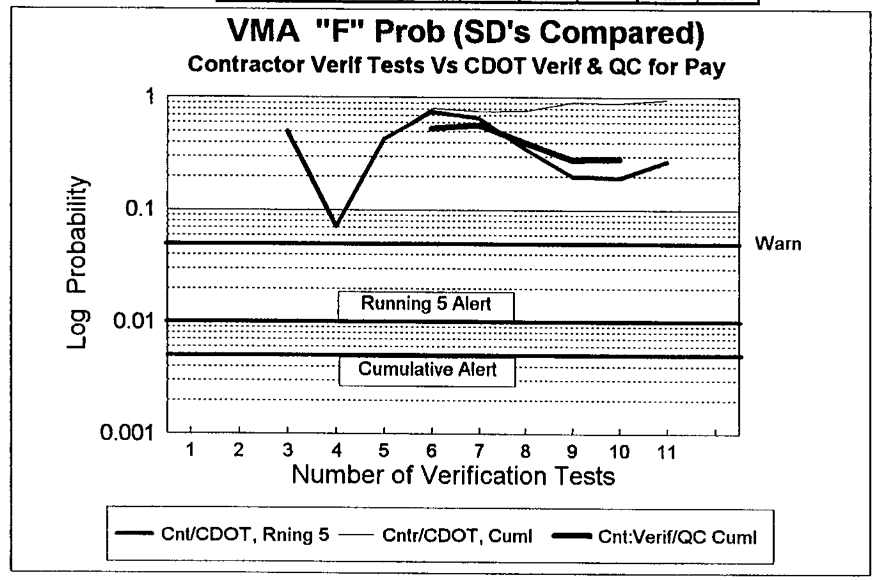


Figure 23

VOIDS MINERAL AGGREGATE: COLO BLVD, MISS - MLK BLVD

Voids Mineral Aggr. Summary	Target		Contr QC	Contr Combined	Contr Verification	CDOT Verification
	14.5	Mean	14.83	14.89	14.98	14.44
		SD	0.36	0.33	0.26	0.26
		"n"	16	27	11	11



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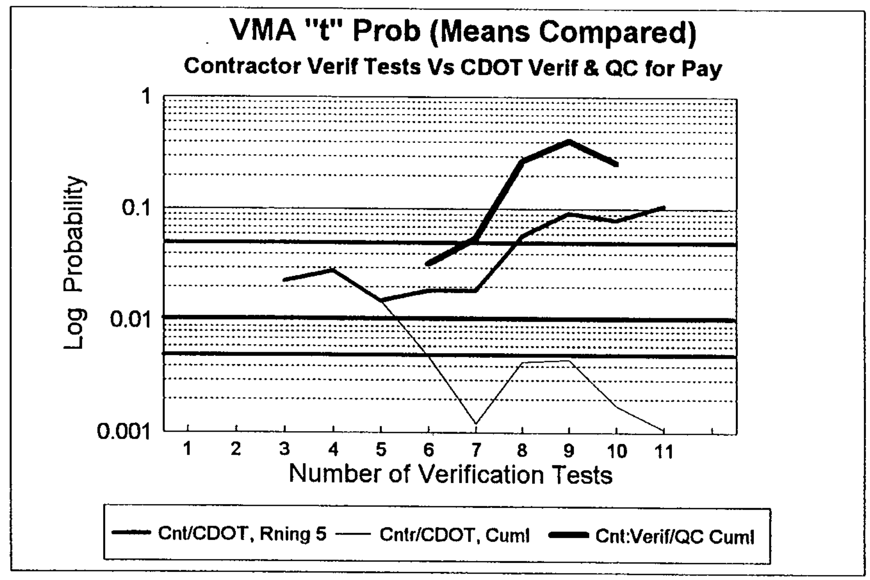

Figure 25

EXPERIMENT RELATING PROBABILITY SLOPES TO "N" FOR "F" AND "t" TESTS

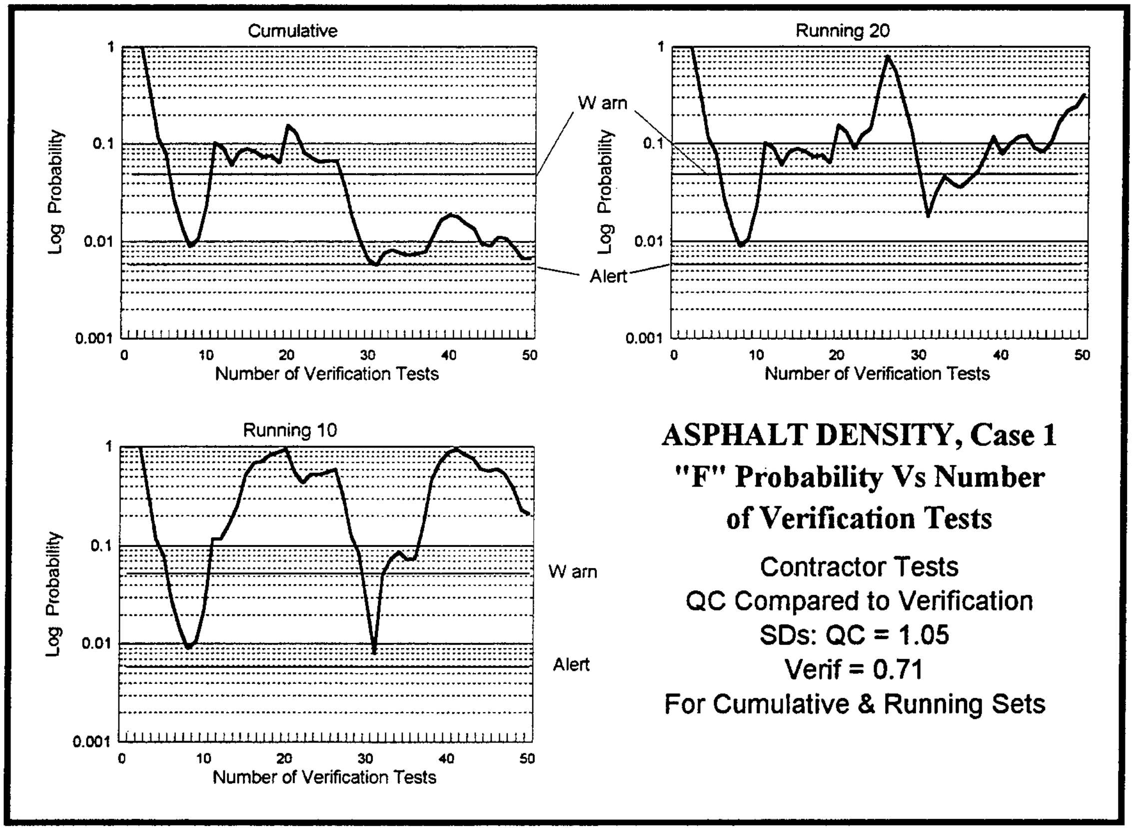

Figure 26

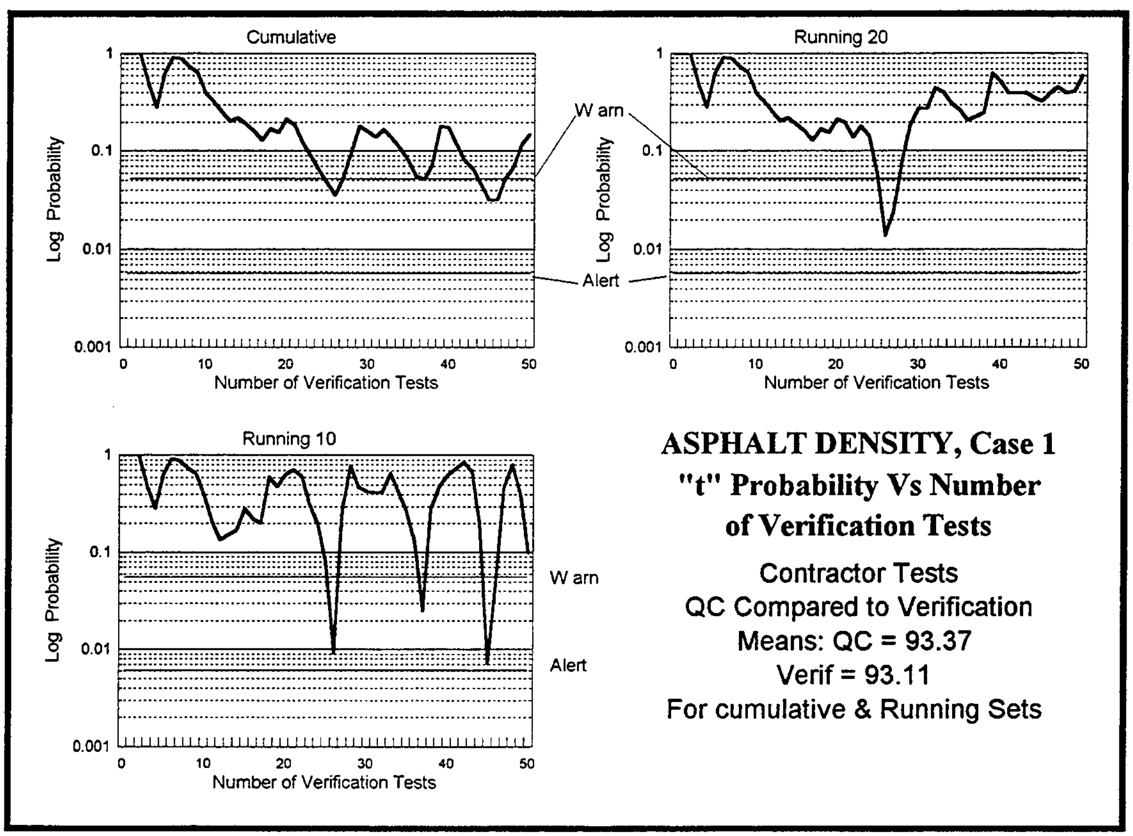

Figure 27

EXPERIMENT RELATING PROBABILITY SLOPES TO "N" FOR "F" AND "t" TESTS

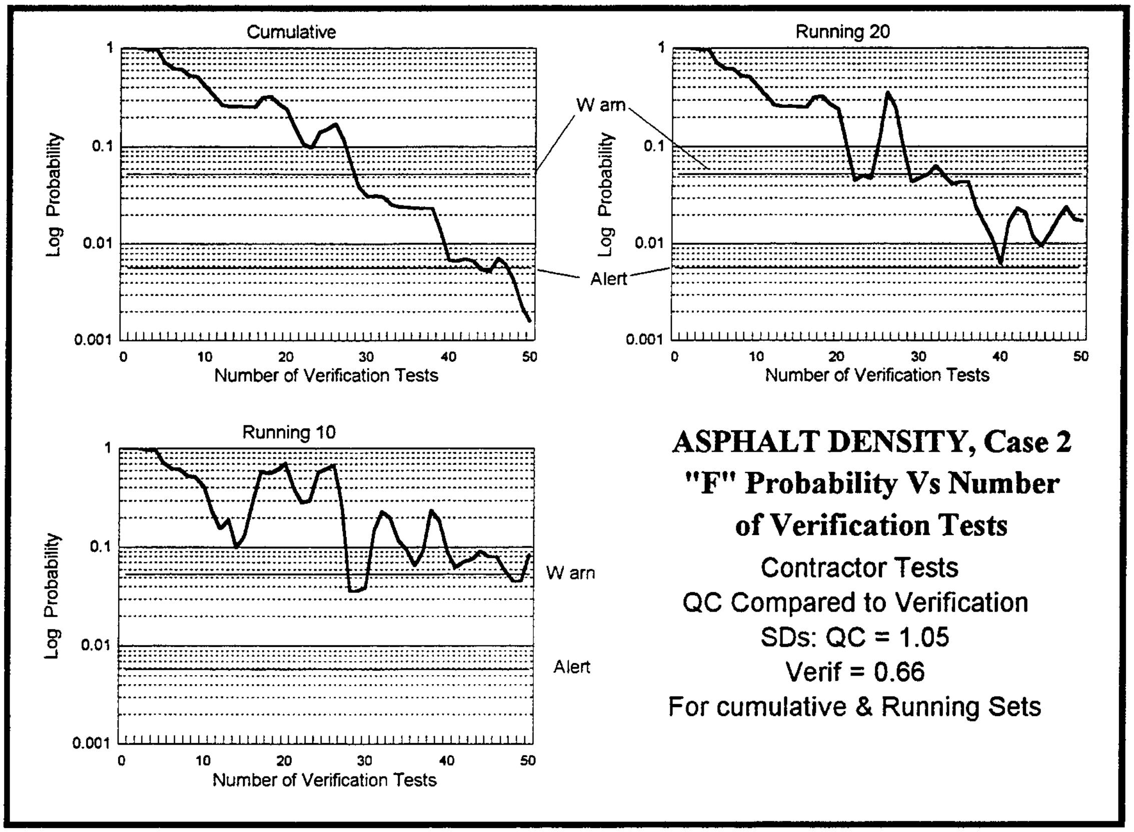

Figure 28

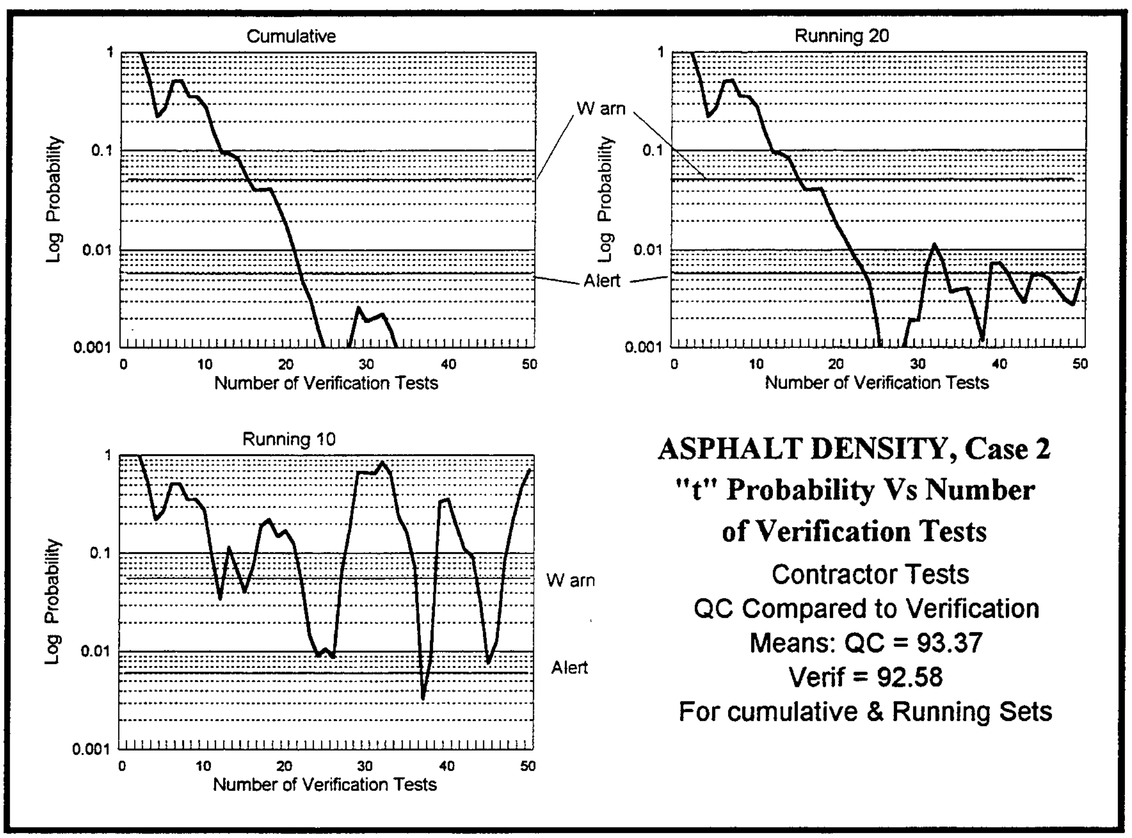

Figure 29

EXPERIMENT RELATING PROBABILITY SLOPES TO "N" FOR "F" AND "t" TESTS

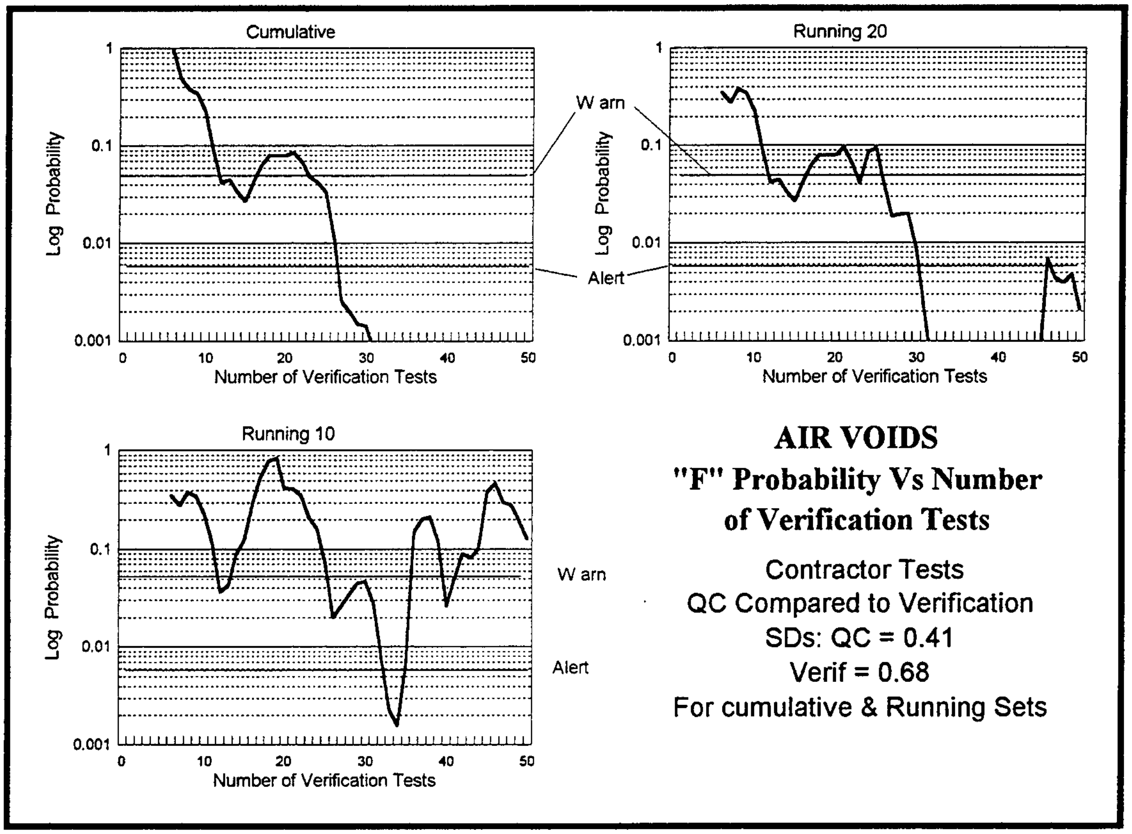

Figure 30

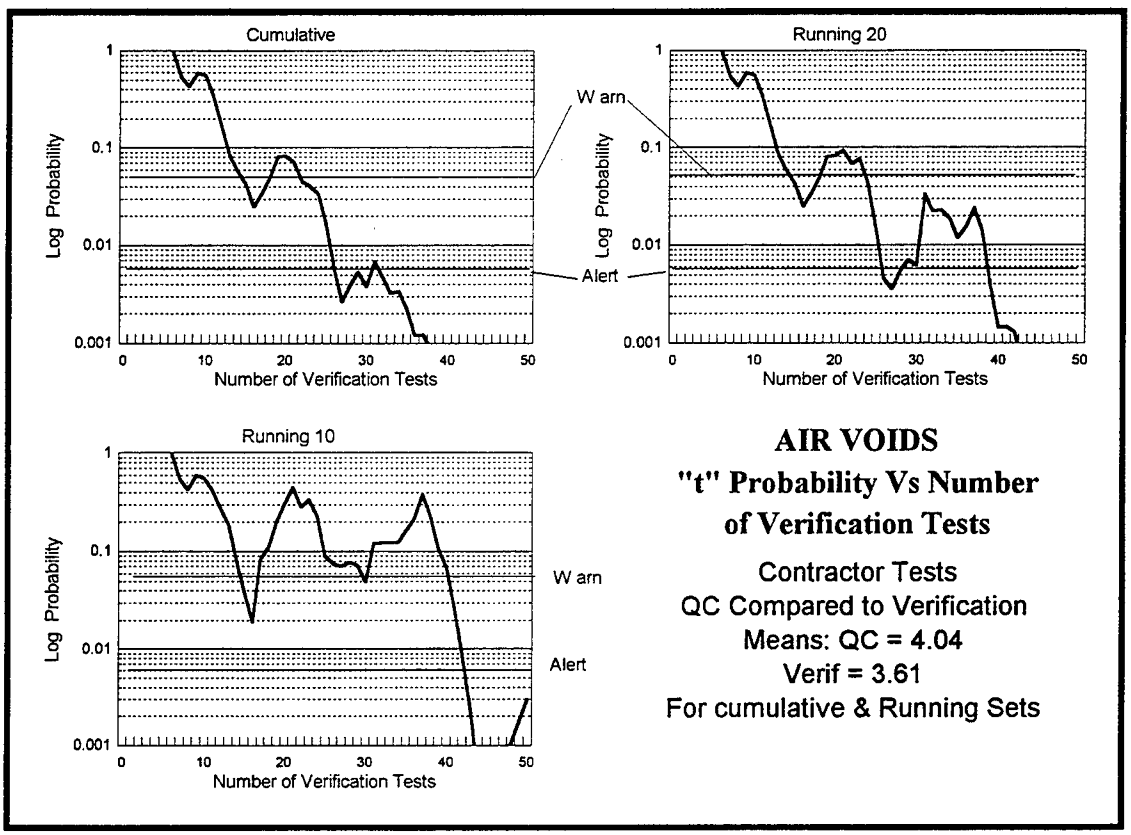

Figure 31

EXPERIMENT RELATING PROBABILITY SLOPES TO "N" FOR "F" AND "t" TESTS

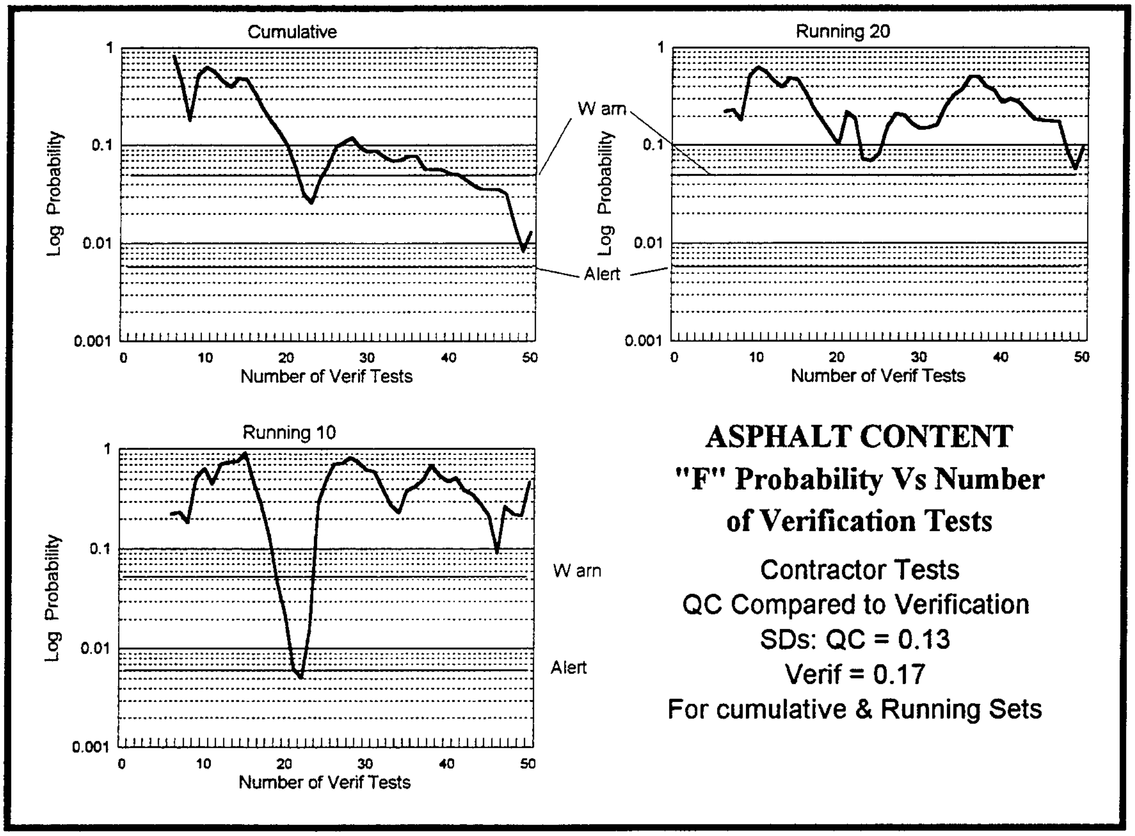

Figure 32

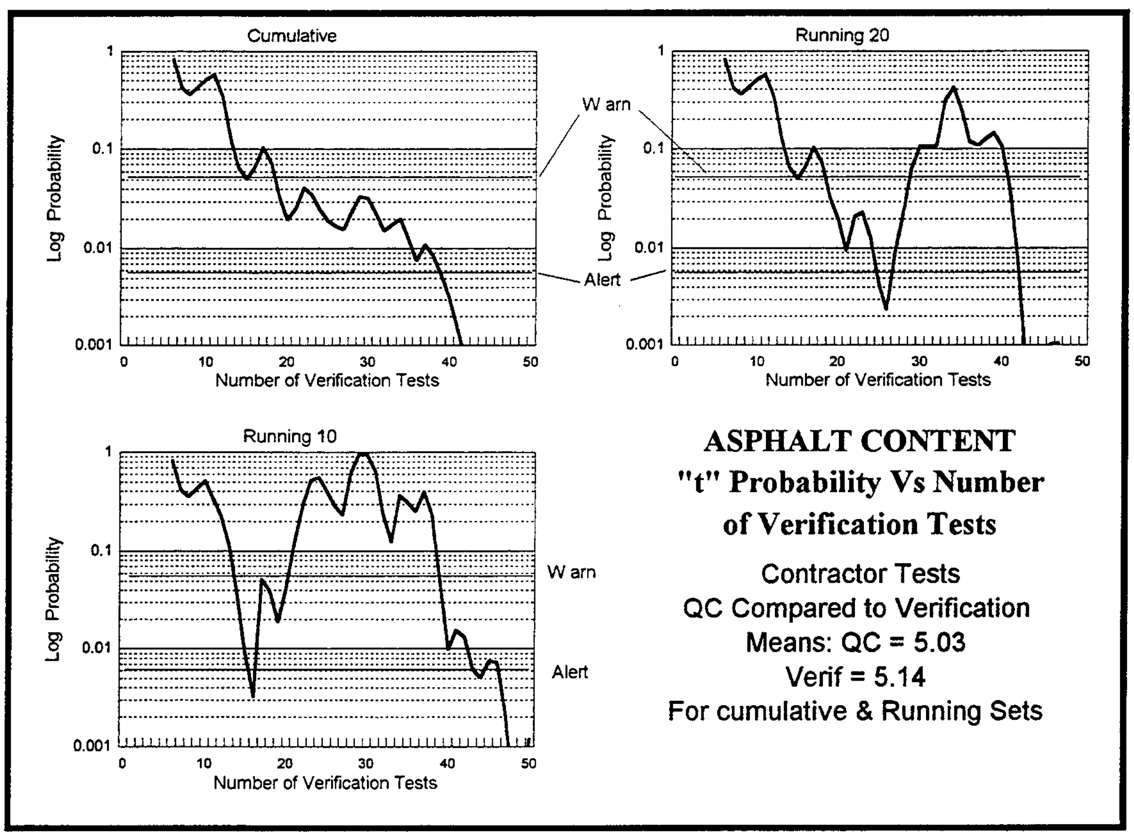

Figure 33

EXHIBIT 1

May 5, 1997

REVISION OF SECTIONS 105 AND 106
VOIDS ACCEPTANCE & QUALITY 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), Furnish Hot Bituminous Pavement and temporary pavement will be determined by tests and evaluations of asphalt content, gradation, in-place density, air voids and voids in the mineral aggregate 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 Contractor and the Department in accordance with Sections 106 and 403 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 as set forth in Section 106 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 either the Contractor's quality control test results or the Department's verification 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 of the Contractor's Quality Control test results for asphalt content, gradation or in-place density greater than the distance 2 x V (see Table 105-1) 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(g). If the material is permitted to remain in place, the PF for the item will not be greater than 0.75.

In the case of in-place density, the Contractor will be allowed to core the exact location of a Quality Control test result more than 2 x V outside the tolerance limit. The result of this core shall be used in lieu of the previous test result. All costs associated with coring will be at the Contractor's expense.

(a) Representing Small Quantities. When it is necessary to represent a process for asphalt cement, gradation or in-place density by only one or two tests 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

$$PF = 1.00 - 0.25[(T_o - T_u)/V]^2$$

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

$$PF = 1.00 - 0.25[(T_L - T_o)/V]^2$$

Where: PF = pay factor.
V = V factor from Table 105-1.
T_o = 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 asphalt content, gradation, or in-place density, the acceptance of the work will be evaluated according to subsection 105.03(g).

(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) Gradation Element. Each specified sieve will be evaluated for QL separately. The lowest QL for any specified sieve will be designated as the QL for gradation element for the process.

(d) Element Pay Factor. Using QL, compute PF, as follows: For asphalt content, gradation and in-place density, the number of random samples (Pn) in each process will determine the pay factor for each element. As test results are accumulated, Pn will change accordingly. When the process has been completed, the number of samples it contains will determine the calculation of PF, based on the formula designated in Table 105-2. Where Pn is greater than 9 and less than 201, PF will be computed by the following formula:

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

Where, when referring to Table 105-2:

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.

Regardless of QL, the maximum PF in relation to Pn is limited according to Table 105-2. For air voids and voids in the mineral aggregate, use the following formula for each process:

$$PF = 0.01619 - 0.14857(QL/100) + 0.15238(QL/100)^2$$

Where: PF = pay factor.
QL = Quality Level

(e) Element Average Pay Factor. A pay factor will be determined for all material or work represented by the elements listed in Table 105-1. For the pay estimates, each individual element will have the average pay factor (PF_A), weighted by the quantities, computed as follows:

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

Where: M_j = Quantity of item represented by the process.
PF_j = The process pay factor.
$\sum M$ = Sum of Quantities, M_1 to M_j (the total quantity).

(f) Composite Pay Factor. When there is more than one element for the item, determine the composite pay factor (PF_C) as follows (at project completion, $\sum M$ used to compute each element PF_A must be numerically the same):

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

Where: W = element factor from Table 105-1.
PF_{Aj} = element average pay factor.
$\sum W$ = sum of the element factors.

The composite pay factor for air voids and voids in the mineral aggregate will be computed separately and then added to the composite pay factor for asphalt content, gradation and in-place density. When the composite pay factor for air voids and voids in the mineral aggregate computes to a value less than zero, then the composite pay factor for air voids and voids in the mineral aggregate will be zero.

As the Contractor's verification and quality control 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 Engineer upon request. Numbers from the calculations will be carried to significant figures and rounded according to AASHTO Standard Recommended Practice R-11.

(g) Evaluation of Work. When the PF_A for all elements in a process are 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 asphalt content, gradation or in-place density is less than 0.75, the Engineer may:

1. Require complete removal and replacement with specification material at no additional cost to the Department; or

2. where the finished product is found to be capable of performing the intended purpose and the value of the finished product is not affected, permit the Contractor to leave the material in place.

If the material is permitted to remain in place the PF_C for the item will not be greater than 0.75. 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.

Table 105-1
"W" and "V" Factors For Various Elements

Element	V factor	W factor
No. 8 mesh and larger sieves	2.80	N/A
No. 30 mesh sieve	1.80	N/A
No. 200 mesh sieve	0.80	N/A
Sieve analysis	N/A	20
Asphalt content	0.20	30
In-place Density	1.10	50
Voids in the Mineral	0.60	50
Air Voids	0.60	50

Table 105-2
Formulas For Calculation PF Based on P_n

Pn	When Pn is as shown at left is 3 to 9, or greater than	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

Subsection 106.03 shall include the following:

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

(a) Quality Control Testing. The Contractor shall be responsible for Quality Control testing on elements as listed in Table 106-1. Quality Control sampling and 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 for assurance of 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 include a schedule showing the locations of samples based on a random stratified sampling frequency, which shall not be less than that shown in Table 106-1.

   B. Test Result Chart. Each quality 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 quality control 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.

   D. F-test and t-test Charts. The results of F-test and paired sample t-test analysis between the Department's verification tests and the Contractors verification tests shall be shown on charts. Another chart shall show the results of F-test and t-test analysis assuming equal variances between the Contractor's verification tests and the Contractor's quality control tests. Each element in Table 106-1 and each required sieve size shall be plotted. The F-test and t-test will be calculated in accordance standard statistical procedures. The F-test and t-test will be calculated on 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 F-test and t-test. A warning value of 5% and an alert value of 1% shall be shown on each chart. 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. Point of Sampling. The material for verification and quality control testing shall be sampled by the Contractor using approved procedures as designated in Section 403. Acceptable procedures are Colorado Procedures. The location where material samples will be taken shall be indicated in the QCP. Both the Contractor's verification tests and the Department's verification tests shall be sampled together at the same location and time. The Engineer shall perform the splitting of samples for verification tests.

3. Testing Standards. The QCP shall indicate which testing standards will be followed. Acceptable standards are Colorado Procedures.

4. Testing Supervisor Qualifications. The person responsible for the Quality Control testing shall be identified in the QCP. This person must possess one or more of the following qualifications:

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

   B. Level A, B, and C certifications from the Laboratory Certification for 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 the LabCAT.

   B. Technicians conducting tests of asphalt content and gradation tests must have Level II B certification from the LabCAT.

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

7. Testing Equipment. Equipment to be used for conducting the Contractor's verification and quality control tests shall be verified in the laboratory intended for use on the project. Equipment verification is intended to identify whether actual apparatus used meets the requirements of this section before testing begins. The Contractor's equipment verification will be conducted by the Colorado Asphalt Paving Association (CAPA). The Contractor shall arrange for verification of the laboratory with enough advance notice so that construction is not delayed. The person responsible for quality control testing and the technicians who will be taking samples and conducting quality control tests are required to attend the verification. The Department's Independent Assurance Tester should also attend. The laboratory shall be assembled and operating as though actual testing were underway when the verification process occurs. Items to be verified are listed on the LabCAT Laboratory Inspection Form. The verification shall be documented on the LabCAT Laboratory Inspection Form and a copy will be provided for the Contractor and the Engineer. All costs for conducting a verification of equipment and laboratory shall be at the Contractor's expense and shall not exceed $450 per trip. Equipment and Laboratory verification will be valid for more than one project if the laboratory does not relocate and the equipment has not been idle for more than 30 days. All of the testing equipment used to conduct quality control testing shall conform to the standards specified in the test procedures and be in good working order. Calibration of the Contractor's nuclear testing devices used for testing of in-place density is a responsibility of the Contractor and shall not be conducted on the Department's calibration blocks.

8. Reporting and Record Keeping. The Contractor shall report the results of the tests to the Engineer in writing at least once per day. The Contractor shall make provisions such that the Engineer can inspect quality control work in progress, including sampling, testing, plants, documentation and the Contractor's testing facilities at any time. The engineer will provide results of the Department's verification tests within on working day.

(b) Verification Testing. Verification testing is the responsibility of the Contractor and the Department according to Table 106-1. 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 shall be in accordance with Table 106-1. The location or time of sampling shall be based on a stratified random procedure. Verification 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 verification and 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. Splitting of verification samples will be performed by the Engineer.

All materials being used are subject to inspection and testing at any time prior to, during, or after incorporation into work. All test results shall be reported directly to the Engineer without prior exchange of information between persons performing the tests. During production, results from split samples of the verification tests will be compared using the paired sample t-test and F-test statistical methods on the five most recent test results. As another test result becomes available, another analysis shall be performed. If an analysis results in a value between 5% and 1%, then a warning exists and the persons performing the tests shall meet to discuss reasons for the warning and solutions to the discrepancy. If an analysis results in a value of 1% or less, then an alert exists and condition red exists. The Engineer will meet with the Contractor to discuss reasons for the alert and recommend actions to be taken.

An analysis of test results will be performed after all test results are known using the t-test and F-test statistical methods. The Contractor's test results will be accepted for pay if the required comparisons of data sets exceed 0.5%. The required comparisons of data shall be:

1. The Department's verification test results and the Contractor's verification test results will be compared using a paired sample t-test and F-test.

2. The Contractor' verification test results and the Contractor's quality control test results shall be compared using a t-test assuming equal variances and F-test.

   If any of the above t-test and F-test analysis show that there is not more than 0.5% probability that the data sets match, then the Department's test data shall be used for determining Quality Levels and Pay Factors according to the methods in this Section.

(c) Testing Schedule. Quality Control, Verification and Independent Assurance testing frequencies shall be in accordance with Table 106-1.

(d) 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 the Contractor's verification and quality control tests of asphalt content, gradation and in-place density. 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:

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 or as described in subsection (b). The Engineer shall be notified immediately in writing and the Quality Control sampling and testing frequency increased to a minimum rate of 1/250 tons for that element. The Quality Control sampling and testing frequency shall remain at 1/250 tons until the MQL reaches or exceeds 78. If the MQL for the next five Quality Control tests is below 65, production will be suspended. After condition red exists, a new MQL will be started.

   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 quality 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.

(e) Resolution of Disputes. The following procedure will be used to resolve disputes when F-test and t-test analysis show that the Contractor's verification test results and CDOT's verification test results are not from the same population:

1. The Engineer will quarter each verification sample into four equal parts. The Engineer will retain two parts, the Contractor shall take one part and the fourth part will be wasted. The Contractor will test one sample. The Engineer will test one part and mark the other part with the verification test number and store in a safe place.

2. At any time during production, if there is a dispute concerning test results of an element, an analysis of the accumulated verification tests shall be performed. The analysis shall be a comparison of results from split samples of the verification tests using the paired sample t-test and F-test statistical methods on all verification tests that have been performed. If the analysis results in a value less than 5%,then a minimum of three samples from the splitting of verification samples that have been stored will be tested by an independent lab chosen by the Engineer. The lab performing independent assurance tests may be selected as the independent lab.

3. The Department's Region Materials Engineer (RME) will review the analysis. If the RME determines that one lab's test results are closer to the independent lab results than the other, then the results of that lab will be used for pay factor calculations up to that point. If the RME can not determine that either lab is closer to the independent lab results, then another group of samples from the splitting of verification samples that have been stored will be tested by the independent lab. If this second analysis is inconclusive, then the Departments's verification test results will be used for pay factor calculations up to that point.

TABLE 106-1
SCHEDULE FOR MINIMUM SAMPLING AND TESTING

ELEMENT	CONTRACTOR QUALITY CONTROL	VERIFICATION TESTS	INDEPENDENT ASSURANCE TESTS
Asphalt Content	1/500 tons (first 2,500 tons, tests 1 to 5, splits to be tested by CDOT and Contractor). Then 1/500-ton substrata (8/4000-ton strata, 7 substrata samples independent of CDOT plus one substrata sample provided from a split of CDOT sample).	1/500 tons, first 2,500 tons. Then 1/4000-ton strata, split of each to be tested by CDOT and Contractor.	1/12,000 tons, By Region Materials Unit
In-Place Density	1/500 tons (first 2,500 tons, tests 1 to 5, at same spot and time by CDOT & Contractor). Then 1/500-ton substrata (2/1000 ton strata, 1 test independent of CDOT plus one substrata test taken at same spot & time as CDOT)	1/500 ton, first 2,500 tons. Then 1/1000-ton strata, each CDOT test to be tested by Contractor at same spot and time.	1/12,000 tons, By Region Materials Unit
Gradation	1/500 tons (first 2,500 tons, tests 1 to 5, splits to be tested by CDOT and Contractor). Then 1/1000-ton substrata (4/4000 ton strata, 3 substrata samples independent of CDOT plus one substrata sample provided from a split of CDOT sample).	1/500 tons, first 2,500 tons. Then 1/4000-ton strata, split of each to be tested by CDOT and Contractor.	1/12,000 tons, By Region Materials Unit
Air Voids and Voids in Mineral Aggregate	1/500 tons (first 2,500 tons, tests 1 to 5, splits to be tested by CDOT and Contractor). Then 1/1000-ton substrata (4/4000 ton strata, 3 substrata samples independent of CDOT plus one substrata sample provided from a split of CDOT sample).	1/500 tons, first 2,500 tons. Then 1/4000-ton strata, split of each to be tested by CDOT and Contractor.	1/12,000 tons, By Staff Materials Branch

Notes:
(1) For each process, the minimum number of verification tests (not including first 2,500 tons) will be at least 5 for asphalt content, gradation, air voids and voids in mineral aggregate. For in-place density the minimum number of verification tests will be 10.
(2) The minimum number of HBP compaction 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 Contractor's quality control tests in that Compaction Test Section.
(3) When unscheduled job mix formula changes are made (CDOT form 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 Note (1). Beginning with the new job mix formula, the quantity it represents shall be estimated. A revised schedule of quality control and verification tests will be based on that estimate.

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
95-18 Widened Slab Study

REPORTS PUBLICATION LIST
CDOT/CTI RESEARCH

94-1 Comparison of the Hamburg Wheel-Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance
1-94 Design and Construction of Simple, Easy, and Low Cost Retaining Walls
94-2 Demonstration of a Volumenteric Acceptance Program for Hot Mix Asphalt in Colorado
2-94 The Deep Patch Technique for Landslide Repair
94-3 Comparison of Test Results from Laboratory and Field Compacted Samples
3-94 Independent Facing Panels for Mechanically Stabilized Earth Walls
94-4 Alternative Deicing Chemicals Research
94-5 Large stone Hot Mix Asphalt Pavements
94-6 Implementation of a Fine Aggregate Angularity Test
94-7 Influence of Refining Processes and Crude Oil Sources Used in Colorado on Results from the Hamburg Wheel-Tracking Device
94-8 A Case Study of concrete Deck Behavior in a Four-Span Prestressed Girder Bridge: Correlation of Field Test Numerical Results
94-9 Influence of Compaction Temperature and Anti-Stripping Treatment on the Results from the Hamburg Wheel-Tracking Device
94-10 Denver Metropolitan Area Asphalt Pavement Mix Design Recommendation
94-11 Short-Term Aging of Hot Mix Asphalt
94-12 Dynamic Measurements or Penetrometers for Determination of Foundation Design
94-13 High-Capacity Flexpost Rockfall Fences
94-14 Preliminary Procedure to Predict Bridge Scour in Bedrock (Interim Report)