IMPLEMENTATION OF A STATISTICALLY BASED QUALITY CONTROL/QUALITY ASSURANCE (QC/QA) PROCEDURE FOR HMA CONSTRUCTION

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by

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ABSTRACT

This report describes the implementation of a statistically based QC/QA system for HMA construction management by the ALDOT. The system was gradually implemented beginning with the 1990 construction season with full implementation during 1992. The process of specification evolution is discussed beginning with the 1990 model specification based on practices in other states. Asphalt content, air voids and mat density measurements made by ALDOT and contractor technicians during implementation are presented, analyzed and discussed in conjunction with specification modifications. The program developed for training and certifying ALDOT and contractor technicians to carry out the required sampling, testing and analysis of results is described and discussed.

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INTRODUCTION

In 1989 the Alabama Highway Department (AHD), now the Alabama Department of Transportation (ALDOT), made the decision to implement a statistically based Quality Control/Quality Assurance (QC/QA) system to manage the construction of hot mix asphalt (HMA). The system was gradually implemented over three construction seasons beginning during the 1990 season with full implementation during the 1992 season.

Motivations for moving from an ALDOT dominated partial end result/partial method specification were two fold. The first was a belief that a cooperative ALDOT/contractor approach to construction management would improve HMA pavement construction quality. Responsibility for mix design, production and placement process required increased skill and knowledge levels for contractor personnel. Elimination of process control responsibilities for ALDOT personnel allowed the focus of their efforts on activities to measure and assure that desired quality was achieved. The second motivation was a belief that this cooperative approach would reduce, or at least prevent growth of, ALDOT manpower requirements for HMA construction management.

This report documents the study conducted by the Auburn University Highway Research Center to assist the ALDOT during implementation of a statistically based QC/QA system for HMA construction management. The Alabama Asphalt Pavement Association and HMA contractors were also major players in this implementation process.

OBJECTIVES

Objectives of the study were as follows:

1. Develop statistically based QC/QA specifications for HMA construction.
2. Collect and analyze data from HMA construction projects.
3. Develop training for ALDOT (QA) and contractor (QC) technicians.

SCOPE

To accomplish project objectives the study included the following tasks:

1. A limited review of state specifications containing QC/QA concepts to establish the basic structure for a model specification to begin the implementation process.
2. Collection and analysis of data from HMA construction projects during the 1990, 1991, 1992 and 1993 construction seasons.
3. Modification of specifications based on the data analyses.
4. Development and presentation of training courses for contractor and ALDOT personnel. Training provided for laboratory technicians, roadway technicians and quality managers during 1990, 1991 and 1992.

SPECIFICATION DEVELOPMENT

ALDOT statistically based specifications for HMA evolved over a 4 year implementation period.

A model specification based on current practices in other states was developed, and applied to 4 trial projects in 1990. Extensive sampling and testing was performed by ALDOT and contractors. The 4 trial projects were managed with existing deterministic specifications, but test results were applied to the model QC/QA specifications. ALDOT and contractor project personnel were apprised of the results, although, no pay adjustments were applied.

Based on experience gained, the model QC/QA specifications were modified. During the 1991 construction season, 11 projects were constructed under the modified QC/QA specifications. The amount of duplicate testing was reduced and pay adjustments applied at one-half the computed rate, i.e., if a pay adjustment of 5% was computed, only a 2.5% adjustment was applied.

Based on experience gained, further modifications were made to the specifications, and a system fully implemented during the 1992 construction season. Final modifications were made prior to the 1993 construction season.

ALDOT specifications were developed by adopting and modifying procedures from other states. Overall systems in most specifications are similar, but specific details are often quite different. Some of the more important details are discussed below.

Mix Properties. It is important to use HMA properties that influence pavement performance for controlling construction processes and accepting material for payment. Control and assurance (acceptance) properties are shown in Table 1.

Table 1. Control and Assurance Properties

Control Properties	Assurance Properties
1. Gradation 2. Asphalt Content 3. Air Void Content 4. Voids Mineral Aggregate 5. Marshall Stability 6. Flow 7. Retained Tensile Strength 8. Mat Density	1. Asphalt Content 2. Air Void Content 3. Mat Density

Control properties are used by the contractor to regulate production and placement processes. Minimum sampling and testing frequencies are specified for the contractors quality control plan, but the contractor may sample and test as often as needed to make necessary adjustments.

Assurance properties are normally a critical subset of control properties and are used to assure that the work being accepted and paid for meets specifications. Definite randomized sampling and testing procedures are established in specifications to assure an unbiased representation of the quality of the mix being produced (asphalt and air voids contents) and of the pavement construction (mat density).

The control and assurance properties in Table 1 were constant throughout specification development. There were, however, changes in sampling and testing frequencies, responsibilities for sampling and testing and type tests used to measure asphalt content and mat density. These changes are illustrated in Table 2, extracted from the 1990 model specification, and Table 3, from the 1993 final specifications.

Sampling Location. Sampling or testing for mat density can only be accomplished on the roadway. Compacted mix on the roadway would also be the logical sampling location for other mix properties as it will most accurately reflect pavement quality. However, there are practical considerations that lead to the decision to sample mix at the plant. These practical considerations include 1) ease of sampling loose mix instead of compacted mat, 2) ease of preparing test specimens from hot loose mix instead of cold compacted cores or slabs, and 3) proximity of sampling points to laboratories. Sampling at plants where laboratories are most often located eliminates the need for transporting samples and provides more timely test results. As demonstrated in Tables 2 and 3 mix was always sampled from loaded trucks at the mix production plant.

Aggregate sampling and testing for gradation control was reduced significantly from 1990 to 1993 (Tables 2 and 3). Aggregate gradation is a control property and final specifications require only contractor stockpile sampling.

Test Procedures. Air voids content is computed with theoretical maximum mix specific gravity and compacted sample bulk specific gravity. Both specific gravities are obtained from standard test procedures. The Rice procedure is used for measuring the theoretical maximum mix specific gravity. The running average of the current and last three theoretical maximum mix specific gravities are used with current bulk gravity measurements to compute air voids content. The use of the running average of four measurements reduces the effects of test variability.

Nuclear gauge or extraction methods may be used for measuring asphalt content. As noted in Table 2, both methods were used in 1990. Based on an analysis of this data, the decision was made to use only the nuclear gauge. The nuclear gauge proved faster, more accurate and more precise than the centrifuge extraction method (1). In addition, exposure to and disposal of potentially dangerous solvents was eliminated.

Table 4, from reference 1, summarizes results from a four laboratory, four mix round robin study of nuclear gauge and extraction asphalt content measurements. Column 3 shows means of differences between measured and prepared asphalt contents. The means indicate nuclear gauges are quite accurate and extraction measurements are consistently low. This is thought due to inability of solvents to completely remove all asphalt, particularly from pores in

Table 2. Sampling and Testing Requirements for 1990 Trial QC/QA Projects

	Control Parameter	Sample Size	Sampling Methods	Sampling Location	Testing Methods	AHD Testing Frequency	Contractor Testing Frequency
1.	Bitumen Content	AHD 319	AASHTO T 168 & AHD 210-90	Loaded Truck	AHD 354	4/day	4/day
2.	Maximum Specific Gravity	8 lb. (4 Kg)	AASHTO T 168 & AHD 210-90	Loaded Truck	AASHTO T 209	* 4 on day one of process start-up and 2/day thereafter	* 4 on day one of process start-up and 2/day thereafter
3.	Air Void Content ** & Marshall Stability & Flow	25 lb. (12 Kg)	AASHTO T 168 & AHD 210-90	Loaded Truck	AHD 353-90	*4 sets of 3 on day one of process start-up & 2 sets of 3/day thereafter	*4 sets of 3 on day one of process start-up & 2 sets of 3/day thereafter
4.	Retained Tensile Strength	25 lb. (12 Kg)	AASHTO T 168 & AHD 210-90	Loaded Truck	AHD 361	1 set of 6 (3 conditioned & 3 control)/ week. Obtain sample on Tuesday or next production day. Treat the day's production as a lot for randomly determining the time for sampling.	1 set of 6 (3 conditioned & 3 control)/week. Obtain sample on Tuesday or next production day. Treat the day's production as a lot for randomly determining the time for sampling.
5.	Extraction+ for Bitumen Content & Gradation	AHD 319	AASHTO T 168 & AHD 210-90	Loaded Truck	AHD 319 and AHD 258	4/day	
6.	Compaction (Density/Voids**)		AHD 210-90	Roadway	AHD 222 for lifts > 300 lbs/ Sq Yd; AHD 350; AASHTO T-166	1/500 lane feet/lift (Nuclear Gage) and 1/1000 lane feet/lift (Core) + +	1/500 lane feet/lift (Nuclear Gage) and 1/1000 lane feet/lift (Core) + +
7.	Stockpile Gradations°	10 lb. (5 Kg)	AASHTO T 2	Stockpile	AASHTO T 11 & T 27	1 per pile per day	1 per pile per day
8.	Cold Feed Gradation°°	10 lb. (5 Kg)	AASHTO T 2 & AHD 150	Cold Feed Belt	AASHTO T 11 & T 27	2 per day	2 per day
9.	Hot Bins (Batch Plants Only)	10 lb. (5 Kg)		Hot Bins	AASHTO T 11 & T 27		2 per day per bin

* Repeated when modifications made to process.

** Voids computed using average maximum specific gravity from the last four tests. When two tests are run per day, the average will include results from the current and previous day's testing. Percent Voids = (100% - % density of maximum theoretical in place)

\+ Ash corrections measured for every specimen.

++ AHD and Contractor measure and compute density and voids from same cores.

° Samples from face where cold feed loading occurring.

°° If RAP is included in mixture, calculate theoretical gradation of final mixture utilizing percent RAP and gradation of RAP stockpile.

Table 3. Sampling and Testing Requirements for QC/QA Projects

Control Parameter	Sample Size	Sampling Methods	Sampling Location	Testing Methods	AHD Testing Frequency	Contractor Testing Frequency
1. Asphalt Content	*	AASHTO T 168 & AHD 210	Loaded Truck +	AHD 354	1 per LOT	++ 1 per set of Marshall samples
2. Maximum Specific Gravity	*	AASHTO T 168 & AHD 210	Loaded Truck +	AASHTO T 209 (Flask determination with dry back)	1 per LOT	++ 1 per set of Marshall samples
3. Air Void Content & VMA ** and Marshall Stability & Flow	*	AASHTO T 168 & AHD 210	Loaded Truck +	AHD 353 & AHD 307 AHD 307	1 per LOT As needed	++ 1 per set of Marshall samples Marshall Stability & Flow - 1 test per production lot
4. Retained Tensile Strength	25 lb. (12 Kg)	AASHTO T 168 & AHD 210	Loaded Truck +	AHD 361	1 set of 6 for each test strip(s) and 1 set of 6 for the next 10,000 tons thereafter 1 set of 6 for each additional 20,000 tons or portion thereafter	1 set of 6 for each test strip(s) and 1 set of 6 for the next 10,000 tons thereafter 1 set of 6 for each additional 20,000 tons or portion thereafter
5. Mixture *** Gradation & Dust to Asphalt Ratio	*	AASHTO T 168 & AHD 210	Loaded Truck +	AHD 371	1 per LOT	1 per set of Marshall samples
6. Mat Compaction		AHD 210	Roadway	AHD 222 & AHD 350 AASHTO T 166	1/2000 lane feet/lift	1/1000 lane feet/lift °° 1/10000 lane ft/lift
7. Stockpile Gradations°	10 lb. (5 Kg)	AASHTO T 2	Stockpile	AASHTO T 11 & T 27 AHD 319 & AHD 258		1/1000 tons/aggregate size

* See AHD 370 for sample size and other requirements.

** Voids and percent theoretical maximum density for mat compaction shall be computed using average maximum specific gravity from the last four tests, including results from the current and previous day's testing. However, if the Contractor's test result for air voids does not compare with the Department's test result, the Contractor shall recompute test results using the individual maximum specific gravity for that particular testing increment and re-compare with the verification test result.

*** If the test results are out of specification tolerance on two consecutive tests for the same size sieve, production shall cease until proper plant adjustments are made.

° Samples shall be taken from stockpile (including RAP) while building or replenishing stockpile. Extractions shall be performed to determine RAP gradations and AC content. Ash corrections shall be measured for every specimen.

°° Cores shall be taken by the Contractor and the density will be determined by the Department.

\+ Beginning each production day, no split sample for acceptance purposes shall be taken prior to the production of 50 tons. If the random number selected falls within the first 50 tons, the sample shall be taken from the first loaded truck following the truck containing the fiftieth ton produced.

++ Testing Frequency:

For mainline paving (including shoulders, ramps, acceleration/deceleration lanes and uniform thickness leveling) unless otherwise noted on the plans.

Testing Increment (Production Time)	Set(s) of 3 Marshall Samples/Day +++
0 - 3.00 hours	1
3.01 - 6.00 hours	2
6.01 - 9.00 hours	3
9.01 - 12.00 hours	4
12.01 - 15.00 hours	5

For other than mainline paving (patching, widening, crossovers, and non-uniform leveling) unless otherwise noted on the plans.

Testing Increment (Tons)	Set(s) of 3 Marshall Samples/Day +++
0 - 400.00	1
400.01 - 800.00	2

+++ When slag is used as an aggregate in the mixture, four (4) Marshall samples shall be compacted. The test result the furthest away from the average of the four test results shall be discarded and the remaining three test results shall be averaged for use in the computation of air voids.

aggregate. Column 4 shows standard deviations and indicates extraction measurements are about 3 times more variable than nuclear gauge measurements.

Table 4. Overall Comparison For Nuclear Gauge vs Extraction Method

Type of Test	Variable Used	Mean	Standard Deviation
Nuclear Gauge	Nuclear Gauge - Prepared	0.02	0.16
Extraction	Extraction Gauge - Prepared	-0.25	0.42

Asphalt content was measured by ALDOT technicians on the four 1990 trial projects. Figure 1, a typical control chart from a project in Jefferson County, confirms that extraction asphalt contents are generally lower than nuclear gauge asphalt contents.

Mat density can be measured with cores or nuclear gauges. Both methods were used in an extensive testing program by both AHD and contractors during the 1990 trial projects (Table 2). After comparative studies of the data obtained (reference 2), the nuclear gauge was selected as the basic measure of mat density. However, because of the significant influence of mat thickness and underlying pavement conditions on nuclear gauge measurements (reference 3), core measurements are still made periodically (Table 3) to check gauge calibration.

Comparison of core and nuclear mat density measurements made during the four 1990 trial projects are summarized in Table 5. In the columns labeled statistics are standard deviations and means of AHD and contractor measurements. Comparisons of the standard deviations provide indications of the variability or precision of the methods. Sixteen comparisons of standard deviations for AHD and contractor measurements reveals 8 cases where nuclear are higher and 8 cases where core are higher. If all data is combined the standard deviations of nuclear gauge measurements is 2.52 and for cores 2.37. These comparisons reveal similar variability or precision for the two methods.

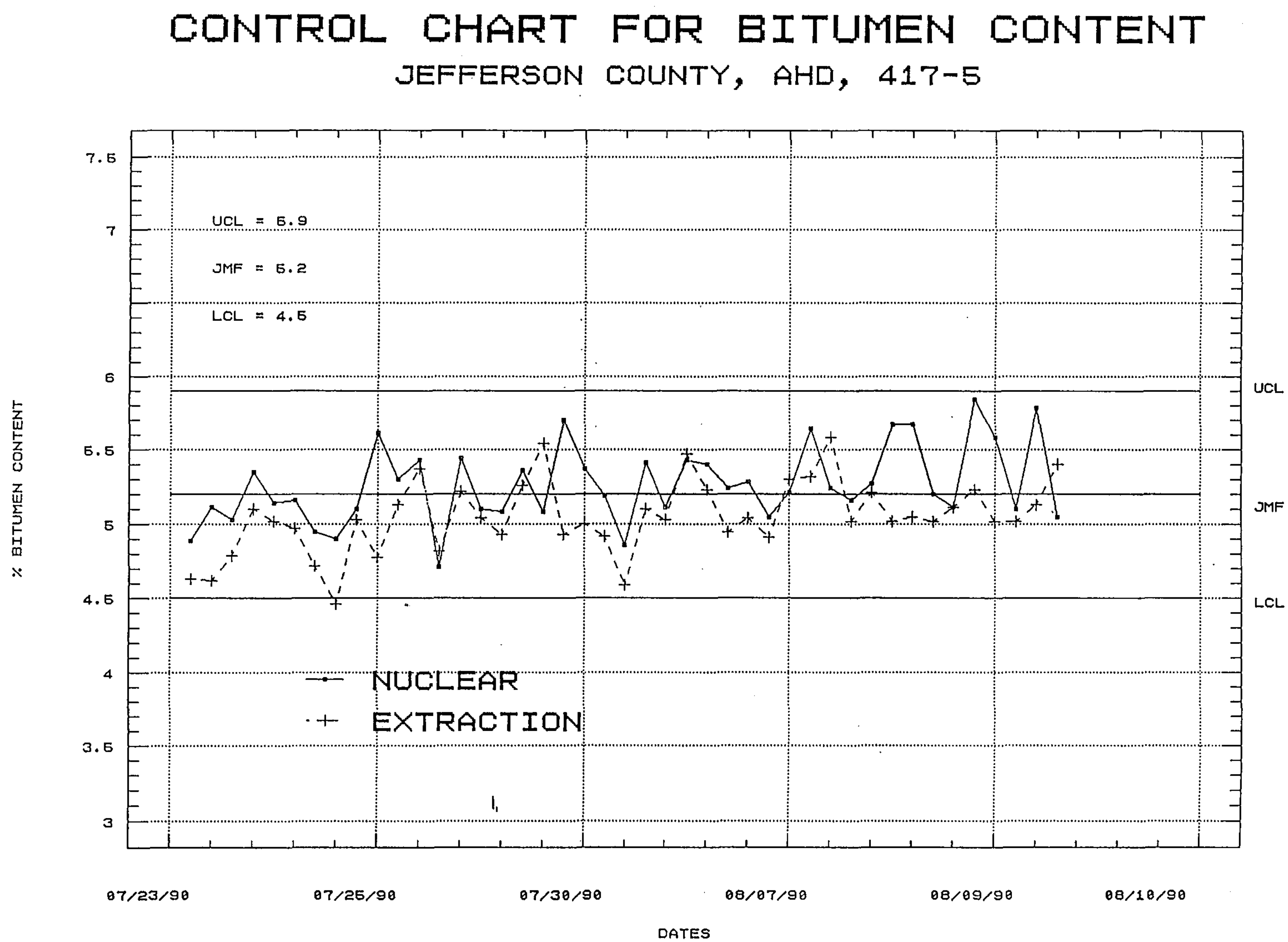

Figure 1. Example Control Chart for Asphalt Content

In the columns labeled ANOVA nuclear gauge and core measurements were statistically compared. Since "known" values were not available, comparisons are relative rather than absolute and provide indications of bias but not accuracy. Comparisons of statistical significance were made at 5% levels and reveal significant differences for 12 of 16 comparisons. However, means for cores were higher for 7 cases and means for the nuclear gauges higher in 9 cases. These comparisons indicate possible difference but no bias for the two methods.

Advantages of nuclear gauges are 1) speed, which reasonably allows more testing, 2) timeliness, which allows almost instant results, and 3) nondestructive testing, which eliminates mat disturbance and the need for patching core holes. These advantages make the nuclear gauge ideal for construction control. Nuclear gauges do, however, have certain disadvantages when compared to the core method. They must be calibrated against core density measurements. The calibration is site specific and changes in mat thickness and/or underlying pavement conditions will reduce nuclear gauge measurement reliability. Cores also provide a "permanent record" which can be maintained and retested as required to resolve conflicts. These attributes make cores ideal for acceptance.

LOT Size and Sampling/Testing Frequency. A LOT is defined as a segment of production sampled and tested for control and acceptance. The basis for delineating a LOT may be time or units of production i.e., for example a days production or 1000 tons of production. SUBLOT size or sampling/testing frequency divides a LOT into increments for determining one value for each acceptance property. Random sampling within each SUBLOT produces a stratified set of samples. A day's production has been the normal definition of a LOT. However, both time and tonnage have been used to stratify LOTS into SUBLOTS for mix sampling and testing. Time was used in 1990, 1991 and 1993 and tonnage in 1992. The final definition of a SUBLOT, as shown in Table 3, was 3 hours production.

Table 5. Comparison of 1990 Nuclear and Core Measurements

Project	Mix	Statistics				ANOVA	
		Nuclear		Core		Nuclear vs Core Means	
		AHD	CON	AHD	CON	AHD	CON
Calhoun/ Cleburne	414	1.78* (149.74)**	1.68 (150.12)	1.88 (151.64)	2.41 (151.37)	[+]S.D. (COR)[o]	S.D. (COR)
	416	1.48 (140.73)	1.23 (140.65)	1.77 (141.58)	1.88 (141.26)	S.D. (COR)	S.D. (COR)
Elmore	414	1.98 (145.79)	1.38 (145.55)	2.07 (146.26)	2.15 (146.84)	[++]S.N.D. (COR)	S.D. (COR)
	416	2.69 (144.32)	1.53 (144.73)	2.06 (143.67)	2.34 (144.75)	S.N.D. (COR)	S.N.D. (NUC)
Jefferson	327	2.76 (149.24)	2.64 (149.19)	1.89 (146.31)	1.84 (146.36)	S.D. (NUC)	S.D. (NUC)
	417	3.84 (148.65)	4.73 (149.06)	3.11 (146.79)	3.12 (146.76)	S.D. (NUC)	S.D. (NUC)
Sumter	414	2.44 (148.86)	2.06 (148.45)	2.35 (146.85)	2.38 (146.83)	S.D. (NUC)	S.D. (NUC)
	417	4.24 (144.79)	3.82 (145.37)	3.36 (144.15)	3.28 (144.10)	S.N.D. (NUC)	S.D. (NUC)

* Standard deviation
** Means in parentheses. Units of lb./ft^3.
\+ Significantly different ($\alpha = 5\%$).
\++ Not significantly different ($\alpha = 5\%$).
o COR or NUC in parenthesis indicates highest mean.

SUBLOT delineation for mat density was always based on length of paving lane. In the 1990 model specification, a SUBLOT was defined as 2000 lane ft. with 4 random stratified samples taken at 500 ft. intervals (Table 2). The final SUBLOT definition was 4000 ft. with 4 random stratified samples taken at 1000 ft. intervals (Table 3).

Acceptance Data. The three properties used for mix acceptance (assurance) remained as listed in Table 1 throughout the implementation process. The agencies (ALDOT or contractor) test results that were used for acceptance did, however, change during implementation. Acceptance is defined as payment for work performed, and specifically, test results used for computing LOT pay factors (percent of unit bid price) changed from ALDOT to contractor.

In a pure QC/QA system, contractor sampling and testing are strictly for process control and owner (ALDOT) sampling and testing are strictly for acceptance. Acceptance in most instances also implies pay adjustments. However, application often deviates from a pure system. The system that evolved during implementation was to use contractor QC data for acceptance, i.e., computation of pay factors. ALDOT test results from a reduced number of samples are used only for verification of contractor test results.

Verification Procedure. Verification of contractor's QC data for QA is accomplished by comparing results from split samples. Acceptable ranges for differences in individual test results are given in Table 6. Mat density is expressed as a percentage obtained by dividing in-place density by theoretical maximum mix density.

Table 6. Acceptable Differences Between Contractor and ALDOT Test Results

Property	Acceptable Range
Asphalt Content	± 0.3%
Aid Void Content	± 0.5%
Mat Density as Percent TMD	± 3.0%

For asphalt and air void contents, mix for each SUBLOT is split into 5 samples. The contractor tests one sample. ALDOT randomly test one SUBLOT sample per LOT. Comparison with contractor results for the same SUBLOT within acceptable ranges in Table 6 is considered verification. Differences outside acceptable ranges requires retesting of the remaining SUBLOT samples until agreement is achieved.

Contractors make a nuclear gauge determinations of mat density on each 1000 paving lane ft. of compacted mat. ALDOT makes a nuclear gauge determination at the same randomly selected location on alternate 1000 paving lane ft. segments. Comparison within the acceptable range in Table 6 is considered verification. Differences outside the acceptable range requires retesting until agreement is achieved.

Acceptance Criteria and Payment Schedules. Acceptance criteria and payment schedules changed dramatically as implementation progressed. These changes are illustrated in Tables 7 and 8 which show acceptance schedules for the 1990 model specifications and the final 1993 specifications, respectively. Changes occurred as the historical data base expanded providing a clearer picture of realistic expectations regarding contractors abilities to meet target values for asphalt content, air voids and mat density and to control variability. The most important change, however, involved a policy decision to pay up to a 2% bonus. This policy was implemented between 1992 and 1993 and the effects will be examined later when pay factor data is analyzed.

While there were changes in acceptance schedules as illustrated by differences in Tables 7 and 8, the methodology for setting acceptance ranges remained the same. Acceptance ranges were set using the formula

$$\text{Acceptance Range} = C_i \sigma_n$$

where

Table 7. Acceptance Schedule from 1990 Model Specifications

Characteristics	Pay Factor	Arithmetic Average of Absolute Difference Between LOT Acceptance Test Values and Job Mix Formula Values.			
		1 Test	2 Tests	3 Tests	4 Tests
Asphalt Cement Content	1.00 0.95 0.90 0.80	0.00 - 0.70 0.71 - 0.80 0.81 - 0.90 over 0.90	0.00 - 0.50 0.51 - 0.57 0.58 - 0.64 over 0.64	0.00 - 0.40 0.41 - 0.46 0.47 - 0.52 over 0.52	0.00 - 0.35 0.36 - 0.40 0.41 - 0.45 over 0.45
Voids in Total Mix (Laboratory Compacted Samples)	1.00 0.95 0.90 0.80*	0.0 - 1.0 1.1 - 2.0 2.1 - 3.0 above 3.0	0.0 - 0.7 0.8 - 1.4 1.5 - 2.1 above 2.1	0.0 - 0.6 0.7 - 1.2 1.3 - 1.7 above 1.7	0.0 - 0.5 0.6 - 1.0 1.1 - 1.5 above 1.5
In-Place Density	1.00 0.95 0.90 0.80	0.0 - 3.0 3.1 - 4.0 4.1 - 5.0 over 5.0	0.0 - 2.4 2.5 - 3.1 3.2 - 3.8 over 3.8	0.0 - 2.2 2.3 - 2.7 2.8 - 3.3 over 3.3	0.0 - 2.0 2.1 - 2.5 2.6 - 3.0 over 3.0

Table 8. Acceptance Schedule from 1993 Specifications

Character-istic	LOT Pay Factor	Arithmetic Average of the Absolute Values of Deviations of the LOT Acceptance Tests From Job Mix Formula Values					
		1 Test	2 Tests	3 Tests	4 Tests	5 Tests	6 Tests
Asphalt Content	1.02 1.00 0.98 0.95 0.90 0.80	0.00-0.28 0.29-0.48 0.49-0.51 0.52-0.57 0.58-0.66 over 0.66	0.00-0.20 0.21-0.34 0.35-0.36 0.37-0.40 0.41-0.47 over 0.47	0.00-0.16 0.17-0.28 0.29-0.29 0.30-0.33 0.34-0.38 over 0.38	0.00-0.14 0.15-0.24 0.25-0.26 0.27-0.28 0.29-0.33 over 0.33	0.00-0.13 0.14-0.21 0.22-0.23 0.24-0.25 0.26-0.30 over 0.30	0.00-0.11 0.12-0.20 0.21-0.21 0.22-0.23 0.24-0.27 over 0.27
Voids in Total Mix (Lab. Compacted Samples)	1.02 1.00 0.98 0.95 0.90 0.80	0.00-0.90 0.91-1.50 1.51-1.62 1.63-1.80 1.81-2.10 over 2.10	0.00-0.64 0.65-1.06 1.07-1.15 1.16-1.27 1.28-1.48 over 1.48	0.00-0.52 0.53-0.87 0.88-0.94 0.95-1.04 1.05-1.21 over 1.21	0.00-0.45 0.46-0.75 0.76-0.81 0.82-0.90 0.91-1.05 over 1.05	0.00-0.40 0.41-0.67 0.68-0.72 0.73-0.80 0.81-0.94 over 0.94	0.00-0.37 0.38-0.61 0.62-0.66 0.67-0.73 0.74-0.86 over 0.86
In-Place Density	1.02 1.00 0.98 0.95 0.90 0.80	0.0-2.0 2.1-3.4 3.5-3.6 3.7-4.0 4.1-4.7 over 4.7	0.0-1.4 1.5-2.4 2.5-2.5 2.6-2.8 2.9-3.3 over 3.3	0.0-1.2 1.3-2.0 2.1-2.1 2.2-2.3 2.4-2.7 over 2.7	0.0-1.0 1.1-1.7 1.8-1.8 1.9-2.0 2.1-2.4 over 2.4		

C_i = constants for the ith pay factor that increase as pay factors decrease

σ_n = standard deviation for sample size n

where

$$\sigma_n = \frac{\sigma_1}{\sqrt{n}}$$

and

σ_1 = standard deviation for sample size 1, i.e., individual measurements.

Selection of constants, C_i, is based on statistical principals to control the probability of an average contractor having LOTs fall in each acceptance range. However, the magnitude of these probabilities, and therefore the magnitude of the constants, is a management decision that sets the desired level of control.

The standard deviation, σ_1, for each parameter provides the historical basis for determining the average ability of contractors to control variability. The analysis of the data collected during implementation showed that the variability of the three assurance properties stabilized after full implementation in 1992.

The procedure for setting acceptance ranges assumes that, on average, target values will be achieved, i.e., if the target (Job mix formula) asphalt content is 5%, the procedure assumes that the average of measured values will be at or near the target. Failure to achieve target values will result in higher probabilities for lower pay factors. The analysis of data collected during implementation showed that accuracy, or the ability to achieve target values, stabilized with full implementation in 1992. The data analysis also showed that, on average, target values were achieved for asphalt content and air voids, but that mat density, as a percentage of TMD, was about 0.6% lower than the 94% target.

Table 7 is the acceptance schedule contained in the 1990 model specification. This table was developed based on a review of practices in 8 states (Florida, Georgia, Virginia, Pennsylvania, Illinois, Wisconsin, Minnesota and Oklahoma), and reflects the QC/QA systems that were being used in these states in 1989 - 1990. The properties, pay factors and ranges used for acceptance were typical. Several of the states also used surface smoothness (as does Alabama) as an acceptance parameter. Surface smoothness is usually handled independently from structural properties, but is the one property where other states have provisions for bonuses.

Table 8 is the acceptance schedule contained in the final 1993 specifications. The acceptance ranges were computed using the procedure described earlier and are based on variabilities computed with data from 1992 projects. As noted earlier variability had stabilized by this time and no significant difference were noted in 1993. Provisions for bonuses up to 2% were added in 1993. This is a unique feature of the Alabama system since bonus payments in the other state systems reviewed were restricted to surface smoothness.

Acceptance ranges for multiple tests may be set based on plus or minus deviations from target values or absolute deviations from target values. The procedure used throughout implementation was to use absolute deviations. This approach was chosen to prevent processes manipulation in order to force mean values toward the target.

Pay factors are computed for each LOT for the 3 assurance properties, but only the smallest applied to adjust the unit bid price for the tonnage in the LOT, i.e., pay factors of 1.00, 0.98 and 0.95 would result in a 5% reduction. This is a middle of the road approach compared to procedures used in some other states. A more severe approach is to apply adjustments cumulatively for all 3 properties, i.e., pay factors of 1.00, 0.98 and 0.95 would result in a 7% reduction in unit bid price. A less severe approach is to apply an average adjustment, i.e., pay factors of 1.00, 0.98 and 0.95 would result in a 3.5% reduction in unit bid price.

DATA COLLECTION AND ANALYSIS

Contractor and ALDOT measurements of asphalt content, air voids and mat density were collected and analyzed during implementation. In addition, pay factor data was collected and analyzed for 1992 and 1993 construction. The data was synthesized into electronic database files using Dbase III Plus. SAS (Statistical Analysis System) was used to sort data from the files and compute various statistics. A complete set of instructions describing procedures used for synthesizing and analyzing data is included as an appendix to this report.

Synthesis of Data and Analysis. To illustrate data file creation and analysis procedures, examples from the appendix are presented here. Table 9 illustrates the structure of a data file for asphalt content and voids. An example for one set of measurements is input in fields 1-9.

Table 9. Asphalt Content/Voids File Structure and Example Input

Field	Field Name	Type	Width	Decimal	Example Input
1	COUNTY	Character	7		Marion
2	ENTITY	Character	3		AHD
3	CON_NAME	Character	6		Dunn
4	MIXSPEC	Character	6		417
5	DATE	Date	8		06/25/93
6	BITCON	Numeric	4	2	6.47
7	BITJMF	Numeric	4	2	6.50
8	VOIDCON	Numeric	4	2	3.68
9	VOIDJMF	Numeric	4	2	4.00
10	ARI_DV_B	Numeric	5	2	
11	ABS_DV_B	Numeric	4	2	
12	ARI_DV_V	Numeric	5	2	
13	ABS_DV_V	Numeric	4	2	

Date for field 10-13 are generated by running programs to manipulate the input data. Differences between measured and target values (JMF asphalt content, 4% voids and 94% TMD) are computed. This is consistent with criteria for determining LOT pay adjustments, which are based on means of absolute differences from target values. Arithmetic differences from target values are computed as

$$\Delta = X_{mea} - X_{jmf}$$

where,

X_{mea} = measured value, and

X_{jmf} = job mix formula (target) value.

Means and standard deviations are computed for arithmetic differences as well as absolute values of the differences. Standard deviations computed with arithmetic differences are the same as standard deviations computed with measured values and, thus provide the same measure of variability or precision. Means of arithmetic differences are numerically equal to differences between means of measured values and target values, i.e.,

$$\overline{\Delta} = \overline{X}_{mea} - X_{jmf}$$

where

$\overline{X}_{mea}$ = mean of measured values

and, thus provide the same measure of accuracy. Means and standard deviations computed for absolute values of differences, $|\Delta|$, provide different measures of accuracy and precision.

Differences and absolute differences for the asphalt content and voids data in Table 9 are shown in Table 10. These values are computed and stored in fields 10-13 of the data file. A portion of a completed asphalt content and voids data file is shown in Figure 2. Data in the files can be sorted in a number of ways and statistics computed for the sorted data bases. Figure 3 is output showing project arithmetic means and standard deviations for eight 1993 projects with

Table 10. Asphalt Content and Voids Differences

Data Base Field	Difference
10. ARI_DV_B	-0.03
11. ABS_DV_B	0.03
12. ARI_DV_V	-0.32
13. ABS_DV_V	0.32

417 mix. Figure 4 illustrates the same computations for the combined 8 projects.

Statistics for pay factors are computed with actual values. Means and standard deviations are computed for pay factors based on asphalt content, air voids, mat density criteria and critical (smallest) LOT pay factors.

Record#	COUNTY	ENTITY	CON_NAME	MIXSPEC	DATE	BITCON	BITJMF	VOIDCON	VOIDJMF	ARI_DV_B	ABS_DV_B	ARI_DV_V	ABS_DV_V
1	MARION	AHD	DUNN	417	06/18/93	6.39	6.50	3.49	4.00	-0.11	0.11	-0.51	0.51
2	MARION	CON	DUNN	417	06/18/93	6.55	6.50	3.75	4.00	0.05	0.05	-0.25	0.25
3	MARION	CON	DUNN	417	06/18/93	6.55	6.50	3.75	4.00	0.05	0.05	-0.25	0.25
4	MARION	AHD	DUNN	417	06/22/93	6.07	6.50	4.52	4.00	-0.43	0.43	0.52	0.52
5	MARION	CON	DUNN	417	06/22/93	6.45	6.50	4.39	4.00	-0.05	0.05	0.39	0.39
6	MARION	CON	DUNN	417	06/22/93	6.30	6.50	4.47	4.00	-0.20	0.20	0.47	0.47
7	MARION	CON	DUNN	417	06/22/93	6.31	6.50	4.35	4.00	-0.19	0.19	0.35	0.35
8	MARION	AHD	DUNN	417	06/23/93	6.64	6.50	3.91	4.00	0.14	0.14	-0.09	0.09
9	MARION	CON	DUNN	417	06/23/93	6.67	6.50	3.92	4.00	0.17	0.17	-0.08	0.08
10	MARION	CON	DUNN	417	06/23/93	6.72	6.50	3.83	4.00	0.22	0.22	-0.17	0.17
11	MARION	CON	DUNN	417	06/23/93	6.55	6.50	3.28	4.00	0.05	0.05	-0.72	0.72
12	MARION	AHD	DUNN	417	06/24/93	6.45	6.50	4.24	4.00	-0.05	0.05	0.24	0.24
13	MARION	CON	DUNN	417	06/24/93	6.47	6.50	3.93	4.00	-0.03	0.03	-0.07	0.07
14	MARION	CON	DUNN	417	06/24/93	6.64	6.50	4.02	4.00	0.14	0.14	0.02	0.02
15	MARION	AHD	DUNN	417	06/25/93	6.51	6.50	3.96	4.00	0.01	0.01	-0.04	0.04
16	MARION	AHD	DUNN	417	06/25/93	6.47	6.50	3.68	4.00	-0.03	0.03	-0.32	0.32

Figure 2: Asphalt Content/Voids Individual Project Data Base File

Analysis Variable : ARI_DV_B

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLMAN	11	11	-0.4100000	0.1200000	-0.1336364	0.1824978
ETOWAH	67	67	-0.5600000	0.4400000	0.0528358	0.1845289
MARION	16	16	-0.4300000	0.2200000	-0.0162500	0.1632534
PICKENS	19	19	-0.4000000	0.2800000	-0.0200000	0.1937065
SHELBY1	43	43	-0.1700000	0.8200000	0.1695349	0.1704888
SHELBY2	13	13	-0.2300000	0.2000000	-0.0461538	0.1339489
WALKER1	28	28	-0.3500000	0.3100000	0.0139286	0.1628983
WALKER2	15	15	-0.3400000	-0.0200000	-0.1586667	0.1070959

Figure 3. Computation of Means and Standard Deviations of Asphalt Content for 1993 Projects with 417 mix

Analysis Variable : ARI_DV_B

N Obs	N	Minimum	Maximum	Mean	Std Dev
212	212	-0.5600000	0.8200000	0.0289151	0.1926794

Figure 4. Computations for 1993 417 Mix Data

Mix and Mat Properties. Table 11 summarizes mix and mat data collected during the 4 year implementation. Each mean and standard deviation represents numerous measurements by contractors and ALDOT technicians on 414, 416 and 417 mixes. The results illustrate the following two important trends:

- Variability and accuracy in achieving target values improved as implementation progressed
- Variability and accuracy stabilized during 1992.

Improved variability is illustrated by decreasing standard deviations and improved accuracy is illustrated by decreasing average deviations from target values. These positive trends are thought due to implementation of the QC/QA procedure, and are a direct result of improved contractor production and placement process control and improved sampling and testing. A final observation from Table 11 is the consistent inability to achieve the target 94% TMD mat compaction. The average deviations for 1992 and 1993 indicate that only about 93.4% is reasonably achievable.

Table 11. Summary of 1990, 1991, 1992 and 1993 Data

Year	Projects	Standard Deviation of Measurements			Average Deviation from Target (Δ=X-X_T)		
		AC (%)	Voids (%)	Mat Density (% TMD)	AC (%)	Voids (%)	Mat Density (% TMD)
1990	4	0.43	1.05	1.69	0.14	0.19	-1.09
1991	11	0.22	0.60	1.91*	0.01	0.13	-1.14*
1992	113	0.20	0.65	1.45	-0.03	0.04	-0.65
1993	107	0.18	0.60	1.19	-0.01	0.00	-0.56

*3 of 11 projects had extremely high variability.

Tables 12-15 provide statistics for a more detailed analysis of asphalt content, voids, nuclear gauge mat density and core mat density, respectively. Observations regarding asphalt content measurements in Table 12 are as follows (3):

- No strong indications that mix type significantly (α = 5%) influenced accuracy or precision of nuclear gauge asphalt content measurements.
- No strong indications that contractor and ALDOT measurements are significantly

(α = 5%) different. However, ALDOT standard deviations and mean deviations from target values are consistently numerically larger than contractors.

- Variability (σ_{AC}) of asphalt content measurements compare well with reported values.

Table 12. Average Δ_{AC} and Standard Deviation σ_{AC}, Asphalt Content

Year	Mix Type	Standard Deviation, σ_{AC}			Mean Deviation, Δ_{AC}		
		AHD	CON	COMB	AHD	CON	COMB
1993	414	0.213	0.174	0.185	-0.001	-0.011	-0.008
	416	0.201	0.169	0.181	-0.019	-0.002	-0.008
	417	0.214	0.179	0.193	0.047	0.018	0.029
	COMB	0.206	0.171	0.183	-0.009	-0.004	-0.006
1992	414	0.228	0.183	0.198	-0.017	-0.019	-0.018
	416	0.241	0.175	0.200	-0.070	-0.023	-0.038
	417	0.187	0.150	0.161	0.007	0.002	0.004
	COMB	0.236	0.175	0.197	-0.054	-0.020	-0.031
1991	414	0.267	0.232	0.246	-0.020	0.064	0.037
	416	0.208	0.212	0.211	-0.036	0.010	-0.009
	417	0.179	0.173	0.174	0.109	0.154	0.141
	COMB	0.226	0.218	0.221	-0.023	0.033	0.012
1990	414	0.443(0.41)*	0.390	0.418	0.150(-0.19)	0.124	0.137
	416	0.561(0.40)	0.547	0.558	0.464(0.17)	0.319	0.392
	417	0.251(0.28)	0.242	0.249	-0.004(-0.30)	-0.087	-0.047
	COMB	0.452(0.41)	0.406	0.430	0.163(-0.16)	0.111	0.137

*Numbers in parentheses are extraction asphalt content measurements by ALDOT.

Extraction asphalt contents were measured by ALDOT technicians on the four 1990 trial projects. Statistics from these measurements are shown in Table 12. Examination of these statistics confirms the observation made earlier (Table 4 and Figure 1) that extractions will give lower asphalt contents than the nuclear gauge. Since there is no known asphalt content for field data, no conclusions can be drawn regarding accuracy of the two methods. Comparison of the standard deviations do not confirm the earlier observation from the round robin study that variability of the extraction method is greater than the nuclear gauge method.

Void content data is tabulated in Table 13. Observations regarding these data are as follows (3):

- No strong indications that the influence of mix type is significant ($\alpha = 5\%$) for variability or relative accuracy of measurements. However, numerically the variability for 416 mix and deviation from target (4%) voids for 417 mix are somewhat larger.
- No strong indications that contractor or ALDOT measurements are significantly ($\alpha = 5\%$) different. However, ALDOT standard deviations and mean deviations from target values are somewhat numerically larger than contractors. These differences are not as pronounced as they are for asphalt content.
- The variabilities (σ_v) of void content determinations compare well with reported values.

Table 13. Average Δ_v and Standard Deviation σ_v, Voids

Year	Mix Type	Standard Deviation, σ_v			Mean Deviation, Δ_v		
		AHD	CON	COMB	AHD	CON	COMB
1993	414	0.622	0.585	0.595	-0.037	0.053	0.049
	416	0.714	0.557	0.614	-0.034	-0.000	-0.012
	417	0.514	0.482	0.495	0.044	-0.149	-0.110
	COMB	0.677	0.565	0.603	-0.014	0.011	0.003
1992	414	0.634	0. 604	0.613	0.071	0.061	-0.064
	416	0.730	0.565	0.624	0.007	0.006	-0.006
	417	0.566	0.506	0.523	0.114	0.106	0.108
	COMB	0.739	0.598	0.646	0.049	0.036	-0.040
1991	414	0.656	0.517	0.564	0.032	0.034	0.033
	416	0.703	0.595	0.626	0.229	0.100	-0.152
	417	0.552	0.397	0.453	0.430	0.202	0.267
	COMB	0.688	0.565	0.605	0.188	0.090	0.130
1990	414	0.130	0.995	1.06	0.358	0.372	0.365
	416	0.884	0.838	0.861	-0.413	0.311	0.367
	417	0.660	0.881	0.791	-0.269	-0.002	-0.013
	COMB	1.085	0.988	1.047	0.160	0.234	0.192

Nuclear gauge mat density data is summarized in Table 14. Observations regarding these data are as follows (3):

- ALDOT and contractor measurements tend to be significantly (α = 5%) different with ALDOT variability and deviation from target values consistently larger. However, as noted in reference 3, comparisons on a project by project basis tend to show significant differences.
- Variabilities for the three mixes tend to be significantly different, and there are strong indications that the variabilities of the thinner surface mixes (416 and 417) are higher than thicker binder (414) mixes.
- The mean deviations from target values (94% TMD) are consistently negative indicating an inability to achieve desired levels of compaction.

Table 14. Average Δ_{ND} and Standard Deviation σ_{ND}, Nuclear Mat Density

Year	Mix Type	σ_{ND}			Δ_{ND}		
		AHD	CON	COMB	AHD	CON	COMB
1993	414	1.434	1.197	1.265	-0.810	-0.475	-0.555
	416	1.385	0.981	1.138	-0.691	-0.509	-0.570
	417	1.536	1.187	1.297	-0.588	-0.446	-0.486
	COMB	1.411	1.076	1.192	-0.710	- 0.492	-0.558
1992	414	1.404	1.001	1.170	-0.944	-0.644	-0.752
	416	1.589	1.296	1.405	-0.783	-0.558	-0.633
	417	2.076	1.836	1.919	-0.784	-0.636	-0.685
	COMB	1.627	1.337	1.445	-0.804	-0.577	-0.653
1991	414	-	1.720	-	-	-1.508	-
	416	-	1.933	-	-	-1.163	-
	417	-	1.147	-	-	-0.035	-
	COMB	-	1.914	-	-	-1.136	-
1990	414	1.407	1.243	1.326	-1.089	-0.943	-1.103
	416	1.947	1.387	1.698	-1.382	-1.130	-1.258
	417	2.499	2.683	2.610	-1.549	-0.940	-1.244
	COMB	1.752	1.623	1.692	-1.215	-0.964	-1.086

The limited core mat density data collected during 1990-1991 are summarized in Table 15. Trends in the core data are similar to the nuclear gauge data.

A detailed analysis was made of a subset of the 1992 nuclear density data to ascertain the effects of 1) milling, 2) surface treatment interlayers and 3) mat thickness on the variability of density measurements and the ability to achieve the specified 94% TMD (3). The important conclusion from this analysis were that 1) milling and surface treatment interlayers significantly reduced mat density variability and 2) milling has the greater effect. The affects of all three factors on the ability to achieve target compaction levels and the effects of mat thickness on density variability were inconclusive. Milling, and to some extent surface treatment layers, increases the uniformity of pavement conditions underlying the mat. This improves the ability of compaction equipment to achieve uniform compaction and the ability of nuclear gauges to provide reliable density measurements.

Table 15. Average Δ_{CD} and Standard Deviation σ_{CD}, Core Mat Density

		σ_{CD}			Δ_{CD}		
Year	Mix Type	AHD	CON	COMB	AHD	CON	COMB
1	414	1.039	1.004	1.032	-1.205	-0.877	-1.045
9	416	1.374	1.580	1.473	-1.075	-1.252	-1.143
9	417	1.009	0.973	0.989	-0.398	-0.326	-0.362
1	COMB	1.311	1.500	1.402	-1.012	1.115	-1.049
1	414	1.706	1.692	1.702	-1.448	-1.241	-1.342
9	416	2.261	1.621	1.971	-1.088	-0.813	-0.951
9	417	2.132	2.151	2.139	-1.881	-1.944	-1.913
0	COMB	1.855	1.765	1.812	-1.451	-1.267	-1.358

<u>Pay Factors</u>. Pay factor data was collected along with mix and mat properties during 1993. After the 1993 construction season was over the division offices were asked to provide available 1992 pay factor data. A partial set was received. This data is summarized in Table 16. Based on the number of LOTs shown in Table 16, the 1992 data base is about one half the size

of the 1993. The 1992 sample size of 698 is, however, sufficient to provide an accurate picture of the effects of the acceptance criteria.

The most obvious observation from Table 16 is the change in mean pay factors. This is the result of the policy change to pay up to a 2% bonus in 1993, i.e., in 1992 the maximum pay factor was 1.00 and in 1993 it was 1.02. In 1992 the average pay reduction for all HMA placed was 0.6% and in 1993 an average bonus of 0.8% was paid. The mean pay factor for the three assurance properties indicate their influences are similar although pay factors for voids and mat density are somewhat smaller than asphalt content.

Table 16. Summary of Pay Factor Analysis

Year	Mean Pay Factors			
	Critical	Asphalt Content	Voids	Mat Density
1992*	0.994	0.999	0.996	0.997
1993**	1.008	1.013	1.012	1.011
	Standard Deviation of Pay Factors			
1992	0.0246	0.0121	0.0207	0.0149
1993	0.0214	0.0158	0.0180	0.0146

* 698 LOTs in 1992
** 1465 LOTs in 1993

The pay factor data was sorted by ALDOT division and by contractor. Ranges, means and standard deviations for ALDOT divisions are shown in Table 17 and for contractors in Table 18. If the divisions with small numbers of LOTs are eliminated, the means in Table 17 are fairly consistent, but the standard deviations vary considerable. The 1993 data for Division 1 is unusual because the smallest pay factor for 119 LOTs was 1.00.

Table 17. Critical Pay Factor Analysis by ALDOT Divisions

Year	Division	N	Minimum	Maximum	Mean	Std. Dev.
1992	2	8	0.80	1.00	0.9450000	0.0730949
	3	157	0.80	1.00	0.9894268	0.0307855
	4	304	0.80	1.00	0.9955921	0.0238597
	5	136	0.95	1.00	0.9982353	0.0087671
	6	33	0.98	1.00	0.9993939	0.0034816
	7	3	1.00	1.00	1.0000000	0
	8	57	0.90	1.00	0.9929825	0.0217095
1993	1	119	1.00	1.02	1.0149580	0.0086234
	2	124	0.90	1.02	1.0116129	0.0169834
	3	244	0.93	1.02	1.0090574	0.0138901
	4	356	0.80	1.02	1.0055337	0.0330513
	5	216	0.90	1.02	1.0099074	0.0140759
	6	72	0.97	1.02	1.0100000	0.0108770
	7	179	0.96	1.02	1.0037989	0.0086819
	8	135	0.98	1.02	1.0108148	0.107239
	9	20	0.80	1.02	0.9710000	0.0612931

If the contractors with only a small number of LOTS are eliminated, in Table 18, the means are reasonably consistent but the standard deviations are rather variable. The 1992 Mid-State, the 1993 Ballew & Roberts, the 1993 Couch, the 1993 Shelby Con., and the 1993 Wilson Brothers data are unusual because of the absence of LOTS with pay reductions.

Table 18. Critical Pay Factor Analysis by Contractor

Year	Company	N	Minimum	Maximum	Mean	Std. Dev.
1992	APAC. AL.	98	0.80	1.00	0.9921429	0.0290485
	APAC GA.	9	0.80	1.00	0.9711111	0.0648931
	ASPHALT CONTRAC	42	0.90	1.00	0.9935714	0.0227201
	BALLEW&ROBERTS	3	1.00	1.00	1.0000000	0
	BURGREEN CON.	5	0.80	1.00	0.9120000	0.0756307
	DUNN CONSTRUCT.	111	0.80	1.00	0.9884685	0.0297932
	EAST AL. PAVING	114	0.80	1.00	0.9968421	0.0211742
	MID-STATE	16	1.00	1.00	1.0000000	0
	MOBILE ASPHALT	10	0.95	1.00	0.9950000	0.0158114
	MCCARTNEY	173	0.80	1.00	0.9971098	0.0181971
	S.T. BUNN	106	0.95	1.00	0.9993396	0.0052133
	WILSON BROTHERS	3	1.00	1.00	1.0000000	0
	WIREGRASS	8	0.95	1.00	0.9875000	0.0205287
1993	APAC AL.	228	0.80	1.02	1.0013596	0.0386375
	APAC-MISS	17	1.00	1.02	1.0141176	0.0093934
	ASPHALT CONTRAC	59	0.98	1.02	1.0066102	0.0106042
	BALLEW&ROBERTS	28	1.00	1.02	1.0092857	0.0097861
	BULLARD EXC.	64	0.96	1.02	1.0018750	0.0092367
	BURGREEN CON.	9	1.00	1.00	1.0000000	0
	COTTINGHAM CON.	13	1.00	1.02	1.0061538	0.0096077
	COUCH INC.	43	1.00	1.00	1.0000000	0
	DUNN CONSTRUCT.	165	0.99	1.02	1.0110303	0.0099771
	EAST AL. PAVING	19	0.80	1.02	1.0114660	0.0189999
	H&L ASPHALT	14	1.00	1.02	1.0142857	0.0093761
	H.O. WEAVER	20	0.80	1.02	0.9710000	0.0612931
	MID-STATE	17	1.00	1.02	1.0058824	0.0087026
	MOBILE ASPHALT	84	0.98	1.02	1.0134524	0.0098781
	MCCARTNEY	94	0.95	1.02	1.0073404	0.0140027
	ROGERS GROUP	47	0.90	1.02	1.0093617	0.0248827
	S&C MATERIALS	8	1.00	1.00	1.0000000	0
	S.T. BUNN	95	0.95	1.02	1.0127368	0.0130826
	SHELBY CON.	79	1.00	1.02	1.0172152	0.0065900
	WHITAKER	49	0.95	1.02	1.0120408	0.0129067
	WILSON BROTHERS	55	1.00	1.02	1.0094545	0.0100771
	WIREGRASS	86	0.97	1.02	1.0087209	0.0102666

TRAINING ACTIVITIES

Contractor and ALDOT technicians must be certified by ALDOT to perform QC/QA sampling and testing, and training was an integral part of the implementation process. The gradual implementation allowed ALDOT and contractors the opportunity to build a pool of certified technicians. Requirements for certification are attendance at a training course, passing a written examination, and a "hands on" demonstration of sampling and testing proficiency. Radiation safety training is also required to operate nuclear asphalt content and density gauges.

Roadway technicians are trained to randomly select locations for density tests, perform nuclear mat density measurements and to take cores. Laboratory technicians are trained to select random samples, sample mix from trucks, split samples, and perform tests (including Rice gravity) and computations for control and assurance properties listed in Table 1.

In addition to roadway and laboratory technician training, training is provided for ALDOT and contractor quality managers. Use of QC/QA data for controlling mix production and placement processes and for computing pay adjustments is emphasized during quality manager training.

As part of this project, seven 1 1/2-day roadway technician, seven 4 - day laboratory technician and one 4 - day quality manager training courses were conducted. In addition, training courses were conducted by the Alabama Asphalt Paving Association. These courses provided training for 672 roadway technicians, 220 laboratory technicians and 141 quality managers by February 1993.

Training is a necessary component of the QC/QA implementation process. Increased sampling and testing requirements creates a need for a larger pool of trained technicians, and use of test results to modify bid prices creates a legal need for formal certification. The need for new technicians remains after implementation as they are lost through natural attrition.

Therefore, training and certification is a continuing and integral part of the QC/QA system.

SUMMARY AND CONCLUSIONS

The successful implementation of the statistically based QC/QA system for HMA construction management was the result of cooperative efforts by ALDOT and HMA contractors. The system has resulted in improved quality of HMA pavement construction. Increased responsibility for and knowledge of production and placement processes has improved contractors ability to provide quality. Systematic training has improved technician sampling and testing skills. Specifications with large sampling and testing requirements provide a clear picture of the quality of mix being produced and placed. To insure that quality levels are maintained/improved, data collection and analysis should be continued and specifications reviewed and updated as necessary. Training and certification should continue to insure availability of a pool of qualified technicians.

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APPENDIX

INSTRUCTIONS FOR SYNTHESIS AND ANALYSIS OF ALDOT HMA QC/QA DATA

INSTRUCTIONS FOR SYNTHESIS AND ANALYSIS OF ALDOT HMA QC/QA DATA

BACKGROUND

The Alabama Department of Transportation began implementing a statistically based quality control/quality assurance (QC/QA) procedure for hot mix asphalt (HMA) in 1990. The implementation was phased in over a three year period with full implementation during the 1992 construction season. The implementation process began with demonstration specifications, which were developed based on a survey of HMA construction procedures in eight states, applied to five projects in 1990. The five demonstration projects were controlled with existing specifications, but data was collected and applied to the QC/QA specifications to illustrate their consequences. The demonstration specifications were modified, based on an analysis of the data collected during 1990, and trial specifications developed. The trial specifications were partially implemented on 11 projects during the 1991 construction season. Based on experience gained during the 1991 partial implementation, the trial specification were modified and procedures fully implemented during the 1992 construction season. Described herein are instructions for synthesis and analysis of the QC/QA data collected and used for control of HMA construction.

PROCEDURE DESCRIPTION

Two commercially available software packages, dBASE III Plus and SAS (statistical Analysis System), are used in the procedure. dBASE III Plus is used for data synthesis. Files are created with pertinent mix design parameters (target values), measured mix and mat properties, and computed pay adjustment factors. SAS is used to sort data and compute various statistics.

Data is input project by project to create data files. Mix properties include asphalt content and air voids. The mat property input is density expressed as a percentage of the theoretical maximum mix density. During construction, mix and mat properties are used to compute pay factors on a LOT by LOT basis. These pay factors for each property, ie, asphalt content, air voids and mat density are input. In addition, critical LOT pay factors (defined as the smallest of the three) are input.

Mix design asphalt contents are input. Target values for air voids, 4%, and mat density, 94% of TMD, are constant.

Identifiers included with the data are project number, county, mix type, ALDOT division and contractor. These identifiers permit sorting of the data for computation and comparison of various statistics.

For analysis of mix and mat properties, differences between measured values and target values are used. This practice is consistent with criteria, contained in the specifications for determining LOT pay adjustments, which are based on means of absolute differences from target values. Arithmetic differences from target values are computed as

$$\Delta = X_{mea} - X_{jmf}$$

where, X_{mea} = measured value, and

X_{jmf} = job mix formula (target) value.

Means and standard deviations are computed for arithmetic differences as well as absolute values of the differences. Standard deviations computed with arithmetic differences are the same as standard deviations computed with measured values and, thus, provide the same measure of variability or precision. Means of arithmetic differences are numerically equal to differences between means of measured values and target values, ie,

$$\bar{\Delta} = \bar{X}_{mea} - X_{jmf}$$

where, $\bar{X}_{mea}$ = mean of measured values

and, thus provide the same measure of accuracy. Means and standard deviations computed for absolute values of differences, $|\Delta|$, provide different measures of accuracy and precision.

Statistics for pay factors are computed with actual values. Means and standard deviations are computed for pay factors based on asphalt content, air voids, mat density criteria and critical LOT pay factors.

INSTRUCTIONS

A. Synthesis of Data

dBASE III Plus and SAS are required for the procedure described below. SAS requires considerable memory and disk space for operation and data storage. A 386 or 486 (SX with math co-processor or DX) is recommended. Data processing also requires 2 disk drives.

Part I. Asphalt Content and Air Void

Files containing asphalt content and voids data are created in dBASE III Plus. Differences between target and measured values are computed with the program "HWDEV.PRG". To create data files for individual projects the following steps are required:

Step 1: Install dBASE III Plus and SAS.

Step 2: Copy program HWDEV.PRG to "C" Drive

Step 3: Create data files and open under dBASE III Plus.

Individual data file may be created on a project by project, county by county, division by division, etc., basis. These can be combined in various ways, as explained later, for analysis. Any name may be used for data files but some standardized coding is recommended. For example, in the file MARAV7D1.DBF "MAR" denotes the county name "MARION", "AV" means asphalt content and void data, "7" represents mix "417", "D" indicates that the project was done by Dunn Construction, and finally, "1" denotes the first job by the contractor.

There are thirteen fields in the asphalt content/voids data file. Table A-1 shows the recommended structure for the dBASE file. The file structure includes the field name, field type, field width and decimal point. The first nine fields are input. The last four fields are filled by running the program "HWDEV" after data is input in the first nine field. The example input data in the first nine fields are also shown in Table A-1.

Table A-1: Asphalt content/Voids file structure and and example input.

Field	Field Name	Type	Width	Decimal	Example Input
1	COUNTY	Character	7		Marion
2	ENTITY	Character	3		AHD
3	CON_NAME	Character	6		Dunn
4	MIXSPEC	Character	6		417
5	DATE	Date	8		06/25/93
6	BITCON	Numeric	4	2	6.47
7	BITJMF	Numeric	4	2	6.50
8	VOIDCON	Numeric	4	2	3.68
9	VOIDJMF	Numeric	4	2	4.00
10	ARI_DV_B	Numeric	5	2	
11	ABS_DV_B	Numeric	4	2	
12	ARI_DV_V	Numeric	5	2	
13	ABS_DV_V	Numeric	4	2	

Step 4: Enter Data

Step 5: Execute HWDEV.PRG

To execute HWDEV the following instructions are necessary:

Strike key "Esc" twice;

Type "GO TOP" and strike "Enter";

Type "SET DEFA TO C" and strike key "Enter";

Type "DO HWDEV" and strike key "Enter".

Program HWDEV computes arithmetic and absolute differences between measured and job mix formula values for asphalt content and voids. Results are stored in the last four fields of the data file as follows:

Data Base Field	Results from "HWDEV"
10. ARI_DV_B	-0.03
11. ABS_DV_B	0.03
12. ARI_DV_V	-0.32
13. ABS_DV_V	0.32

Step 6: Print Database

After HWDEV has been executed the asphalt content/voids data file is complete, and may be printed as shown in Figure A-1. In the last four headings, "B" denotes asphalt content and "V" denotes void.

Part II. Mat Density

The basic procedure for synthesizing mat density is the same as that for asphalt content and air void. A few specifics are modified to fit mat density data.

To create mat density data files the following steps are required:

Step 1: Install dBASE III Plus and SAS.

Step 2: Copy program MATDEV.PRG to "C" Drive

Step 3: Create data files and open under dBASE III Plus.

The procedures to create data file are the same as for asphalt content and voids.

There are eight fields in the mat density data file. The recommended dBASE file structure is shown in Table A-2. The first six, as illustrated in Table A-2, are input and the last two are computed by the program MATDEV.PRG.

Table A-2: Mat Density file structure and example input.

Field	Field Name	Type	Width	Decimal	Example Input
1	COUNTY	Character	8		Franklin
2	ENTITY	Character	3		AHD
3	CON_NAME	Character	7		Ballew
4	MIXSPEC	Character	6		417
5	DATE	Numeric	8		08/28/93
6	NUCDENSITY	Numeric	6	2	93.3
7	ARI_DV_N	Numeric	7	2	
8	ABS_DV_N	Numeric	6	2	

Step 4: Enter Date

Step 5: Execute MATDEV

To execute MATDEV the following instructions are necessary:

Strike key "Esc" twice;

Type "GO TOP" and strike key "Enter";

Type "SET DEFA TO C" and strike key "Enter";

Type "DO MATDEV" and strike key "Enter".

Program MATDEV computes arithmetic and absolute difference between target (94%) and measured mat density. Mat densities are expressed as a percentage of the theoretical maximum (Rice) densities. Difference are stored in the last two fields of the data bases as follows:

Data Base Field	Results from "MATDEV"
7. ARI_DV_N	-0.70
8. ABS_DV_N	0.70

Step 6: Print Database

Execution of MATDEV completes the mat density data base and it may be printed as shown in Figure A-2.

Part III. Pay Factors

The basic procedure for synthesizing pay factor data is the same as described above for asphalt content, voids and mat density. A few specifics are modified to fit pay factor data and analysis procedure. One of these modifications is that pay factor values, rather than differences between measured and target values, are the variable used for analysis. This eliminates the need for programs to calculate differences. A second difference is that pay factors are for LOT's (normally a day's production) and were computed using the results from more than one test result for each control parameter, ie, asphalt content, voids and mat density. Therefore, the volume of data will be reduced by a factor of about three. For identification and sorting, contractors are identified with a 15 symbol variable. A listing used in creating 1992 and 1993 data bases is shown in Table A-3. Additional contractors can be added as needed.

Table A-3: List of contractor identifications.

S.T.BUNN	H&L ASPHALT
ROGERS GROUP	APAC-MISS
BALLEW&ROBERTS	MID-STATE
DUNN CONSTRUCT.	ASPHALT CONTRAC
BURGREEN CON.	EAST AL. PAVING
SHELBY CON.	MOBILE ASPHALT
APAC AL.	H.O. WEAVER
COTTINGHAM CON.	S&C MATERIALS
MCCARTENEY	WILSON BROTHERS
WHITAKER	APAC GA.
WIREGRASS	BULLARD EXC.
COUCH INC.	

To create pay factor data files the following steps are required:

Step 1: Install dBASE III Plus and SAS

Step 2: Create data files and open under dBASE III Plus

The procedures for creating pay factors data files are the same as described previously for asphalt content, voids and mat density. There are eleven fields in the data file. The structure for dBASE file is shown in Table A-4. All the necessary information can be found on QC/QA Form 3. Example input for one LOT is also shown in Table A-4.

Table A-4: Pay factor file structure and example input.

Field	Field Name	Type	Width	Decimal	Example Input
1	DIVISION	Character	2		1
2	COMPANY	Character	15		Shelby Con.
3	PROJECT	Character	15		301-224-069-301
4	PAY_ITEM	Character	8		414
5	LOT	Character	3		1
6	TONNAGE	Numeric	8	2	879.33
7	PF_AC	Numeric	4	2	1.02
8	PF_VOID	Numeric	4	2	1.02
9	PF_MAT	Numeric	4	2	1.01
10	PF_CRITI	Numeric	4	2	1.01
11	YEAR	Numeric	4	2	93

Step 3: Print Database

Entry of data completes the pay factor data file and it may be printed as shown in Figure A-3. Figure A-3 shows a part of Division 5 pay factor data for the year 1992.

B. Analysis of Data

Data files created in dBASE III Plus are analyzed in SAS. Analysis techniques for asphalt content / voids and mat density ,described below in Part I, are different from analysis techniques for pay factor, described in Part II.

Part I. Asphalt content/Voids and Mat Density

The general steps followed to analyze asphalt content, voids and mat density data are illustrated in the flow chart in Figure A-4. dBASE III Plus is used to manage the data and SAS is used to calculate minimum and maximum values, means and standard deviations for differences between measured and target values for asphalt content, voids and mat density. Four main steps, as illustrated below are followed for data analysis. dBASE is used for steps 1-3 to sort the data and prepare files for SAS. SAS is used in step 4 to compute the statistics described above. An alternative approach is also shown in a flow chart in Figure A-5. In the alternative approach, steps 3 and 4 are performed in one step by SAS. The sorting and combining of data in step 3 is simpler in SAS than in dBASE, but the size of the data file that can be efficiently handled is limited.

Primary Approach

Step 1:

Individual files are created as described earlier by dBASE to store data. Individual files were created on a project by project basis but may be created for any basis such as county by county, division by division, etc. Each file contains either asphalt content & air void data or mat density data.

Step 2:

Data from individual files are complied and sorted to produce files for the three different types of ALDOT mixes; namely 414, 416 & 417. Files for the three types of mix data are combined into in one file, so there will be four files identified as COMBINE, 414, 416 & 417 in the flow chart. Table A-5 shows suggested file names created in step 2.

Table A-5: Example File Names.

Property	Mix Type	File Name
AC & Voids	Mix 414	AV414.DBF
	Mix 416	AV416.DBF
	Mix 417	AV417.DBF
	All Mixes	AVCOM.DBF
Mat Density	Mix 414	MD414.DBF
	Mix 416	MD416.DBF
	Mix 417	MD417.DBF
	All Mixes	MDCOM.DBF

Step 3:

Each of the above four files are further organized into two additional files one with Alabama DOT measurements (AHD) and another with contractor measurements (CON). As a result, there were 12 different files used by SAS to calculate statistics. Table A-6 shows suggested file names created in steps 2 & 3.

Table A-6: Name of the files to be used by SAS programs.

Mix Type	Agency	AC & Voids	Mat Density
Mix 414	AHD+CON	AV414.DBF	MD414.DBF
	AHD	AAV14.DBF	AMD14.DBF
	CON	CAV14.DBF	CMD14.DBF
Mix 416	AHD+CON	AV416.DBF	MD416.DBF
	AHD	AAV16.DBF	AMD16.DBF
	CON	CAV16.DBF	CMD16.DBF
Mix 417	AHD+CON	AV417.DBF	MD417.DBF
	AHD	AAV17.DBF	AMD17.DBF
	CON	CAV17.DBF	CMD17.DBF
All Mixes	AHD+CON	AVCOM.DBF	MDCOM.DBF
	AHD	AAVCM.DBF	AMDCM.DBF
	CON	CAVCM.DBF	CMDCM.DBF

The sorting and combining procedure described in steps 2 and 3 was used in the analysis of 1990-1993 data. Other schemes for sorting and combining are possible and are limited only by the data in individual data files as illustrated in

Figures A-1 and A-2. For example, the files for years 1990-1993 could be combined and then sorted according to contractor. One bit of data not included in 1990-1993 asphalt content/voids and mat density files, but should be included in subsequent files is division number. Inclusion of division number will allow sorting of data and calculation of statistics by division. Division number is included as an identifier in pay factor data files (Figure A-3).

Step 4:

SAS calculates statistics for each of 12 files. The statistics calculated are minimum and maximum values, means and standard deviations. Two types of SAS programs (Type I & Type II) are provided to calculate statistics. Type I calculate statistics for arithmetic and absolute differences for each project or county. Type II calculate statistics for the combined data. Table A-7 shows the name of the programs used to calculate the different combinations of data. For an example, program MDARIP.PGM is used to calculate the statistics for arithmetic deviations of mat densities on a project by project basis. Figures A-6 - A-17 show examples of output obtained using the programs listed in Table A-7.

Table A-7: Name of the programs for AC, VOIDS and Mat Density.

Property	Program Type	Deviation Type	Program Name	Example Output
AC	Type I	Arithmetic	ACARIP.PGM	Figure A-6
		Absolute	ACABSP.PGM	Figure A-7
	Type II	Arithmetic	ACARIC.PGM	Figure A-8
		Absolute	ACABSC.PGM	Figure A-9
VOIDS	Type I	Arithmetic	VDARIP.PGM	Figure A-10
		Absolute	VDABSP.PGM	Figure A-11
	Type II	Arithmetic	VDARIC.PGM	Figure A-12
		Absolute	VDABSC.PGM	Figure A-13
MAT DENSITY	Type I	Arithmetic	MDARIP.PGM	Figure A-14
		Absolute	MDABSP.PGM	Figure A-15
	Type II	Arithmetic	MDARIC.PGM	Figure A-16
		Absolute	MDABSC.PGM	Figure A-17

The text of program ACARIP.PGM is shown in Figure A-18. All other programs are similar except for minor changes. Two points need to be mentioned about use of the programs.

1. Line 1 is used for the title. This title is printed in the output file. Anything convenient may be written inside the inverted commas in line 1 and it will be printed as heading on the output.

2. Line 3 is used to specify the file name containing the data to be analyzed. The portion " 'a:\XXXXX.dbf' " is used to specify the file name. "a:" is the Drive where the data file is stored. "XXXXX" is the name of the file and "dbf" is the

common extension for dBASE files. These changes are made before running the program.

Alternative Approach

The flow chart for the alternative approach is shown in Figure A-5. Steps 1 and 2 to create four files (COMBINE, 414, 416 and 417) in dBASE are the same as in primary approach. Step 3 and Step 4 in the primary approach are combined, and performed by SAS as step 3 as described below.

Step 3:

Each of the above four files are analyzed by SAS programs to calculate statistics. Four programs for different combinations of data are described below

i). Program Type I calculates statistics for each project or county.

ii). Program Type II calculates statistics for each project or county with data separated according to AHD and contractor.

iii). Program Type III calculates statistics for all data in a file.

iv). Program Type IV calculates statistics for all data sorted according to AHD or contractor data.

In this approach some advanced SAS programming techniques are used. By using advanced techniques in the programs, different combinations of analysis may be done in a single step.

Table A-8 lists the programs provided for use in the alternative approach. The basic structure of all the programs are same. Only minor editing was done to modify the programs to fit a specific analysis.

Table A-8: List of the programs for alternative approach.

Property	Program Type	Program Name	
		Arithmetic Deviation	Absolute Deviation
AC	Type I	AACARI1.PGM	AACABS1.PGM
	Type II	AACARI2.PGM	AACABS2.PGM
	Type III	AACARI3.PGM	AACABS3.PGM
	Type IV	AACARI4.PGM	AACABS4.PGM
VOIDS	Type I	AVDARI1.PGM	AVDARI1.PGM
	Type II	AVDARI2.PGM	AVDABS2.PGM
	Type III	AVDARI3.PGM	AVDABS3.PGM
	Type IV	AVDARI4.PGM	AVDABS4.PGM
MAT DENSITY	Type I	AMDARI1.PGM	AMDABS1.PGM
	Type II	AMDARI2.PGM	AMDABS2.PGM
	Type III	AMDARI3.PGM	AMDABS3.PGM
	Type IV	AMDARI4.PGM	AMDABS4.PGM

Part II. Pay Factor

Pay factor data files created in Part A are analyzed directly by SAS. The approach is similar to the Alternative approach for AC, Voids and Mat density but, due to differences in the structure of data files, the SAS analysis is little different. One type of program is used to calculate the statistics for the variables PF_CRITI, PF_AC, PF_VOID and PF_MAT. The statistics are minimum & maximum values, means and standard deviations. The analysis may be done on different basis for example, division by division, project by project or company by company. Table A-9 lists program names to be used for the different analyses and figures containing example output.

Table A-9: Name of the programs for pay factor analysis.

Basis	Program Name	Example Output
Division	PFDIV.PGM	Figure A-19
Company	PFCOM.PGM	Figure A-20
Project	PFPRJ.PGM	Figure A-21

Figure A-22 is the text of program PFDIV.PGM. As described earlier, only the printout heading in line 1 and file name in line 3 needs to be edited before running the SAS program.

Record#	COUNTY	ENTITY	CON_NAME	MIXSPEC	DATE	BITCON	BITJMF	VOIDCON	VOIDJMF	ARI_DV_B	ABS_DV_B	ARI_DV_V	ABS_DV_V
1	MARION	AHD	DUNN	417	06/18/93	6.39	6.50	3.49	4.00	-0.11	0.11	-0.51	0.51
2	MARION	CON	DUNN	417	06/18/93	6.55	6.50	3.75	4.00	0.05	0.05	-0.25	0.25
3	MARION	CON	DUNN	417	06/18/93	6.55	6.50	3.75	4.00	0.05	0.05	-0.25	0.25
4	MARION	AHD	DUNN	417	06/22/93	6.07	6.50	4.52	4.00	-0.43	0.43	0.52	0.52
5	MARION	CON	DUNN	417	06/22/93	6.45	6.50	4.39	4.00	-0.05	0.05	0.39	0.39
6	MARION	CON	DUNN	417	06/22/93	6.30	6.50	4.47	4.00	-0.20	0.20	0.47	0.47
7	MARION	CON	DUNN	417	06/22/93	6.31	6.50	4.35	4.00	-0.19	0.19	0.35	0.35
8	MARION	AHD	DUNN	417	06/23/93	6.64	6.50	3.91	4.00	0.14	0.14	-0.09	0.09
9	MARION	CON	DUNN	417	06/23/93	6.67	6.50	3.92	4.00	0.17	0.17	-0.08	0.08
10	MARION	CON	DUNN	417	06/23/93	6.72	6.50	3.83	4.00	0.22	0.22	-0.17	0.17
11	MARION	CON	DUNN	417	06/23/93	6.55	6.50	3.28	4.00	0.05	0.05	-0.72	0.72
12	MARION	AHD	DUNN	417	06/24/93	6.45	6.50	4.24	4.00	-0.05	0.05	0.24	0.24
13	MARION	CON	DUNN	417	06/24/93	6.47	6.50	3.93	4.00	-0.03	0.03	-0.07	0.07
14	MARION	CON	DUNN	417	06/24/93	6.64	6.50	4.02	4.00	0.14	0.14	0.02	0.02
15	MARION	AHD	DUNN	417	06/25/93	6.51	6.50	3.96	4.00	0.01	0.01	-0.04	0.04
16	MARION	AHD	DUNN	417	06/25/93	6.47	6.50	3.68	4.00	-0.03	0.03	-0.32	0.32

Figure A-1: Asphalt content/air voids individual project data base file.

Record#	COUNTY	ENTITY	CON_NAME	MIXSPEC	DATE	NUCDENSITY	ARI_DV_N	ABS_DV_N
1	FRANKLIN	AHD	BALLEW	416A	08/28/93	93.30	-0.70	0.70
2	FRANKLIN	AHD	BALLEW	416A	08/28/93	95.00	1.00	1.00
3	FRANKLIN	AHD	BALLEW	416A	08/28/93	94.20	0.20	0.20
4	FRANKLIN	AHD	BALLEW	416A	08/28/93	91.10	-2.90	2.90
5	FRANKLIN	AHD	BALLEW	416A	08/28/93	94.30	0.30	0.30
6	FRANKLIN	AHD	BALLEW	416A	08/28/93	91.10	-2.90	2.90
7	FRANKLIN	AHD	BALLEW	416A	08/28/93	94.00	0.00	0.00
8	FRANKLIN	AHD	BALLEW	416A	08/28/93	93.30	-0.70	0.70
9	FRANKLIN	AHD	BALLEW	416A	08/28/93	94.60	0.60	0.60
10	FRANKLIN	AHD	BALLEW	416A	08/27/93	95.00	1.00	1.00
11	FRANKLIN	AHD	BALLEW	416A	08/27/93	92.10	-1.90	1.90
12	FRANKLIN	AHD	BALLEW	416A	08/27/93	96.30	2.30	2.30
13	FRANKLIN	AHD	BALLEW	416A	08/27/93	95.20	1.20	1.20
14	FRANKLIN	AHD	BALLEW	416A	08/27/93	93.20	-0.80	0.80
15	FRANKLIN	AHD	BALLEW	416A	08/27/93	93.60	-0.40	0.40
16	FRANKLIN	AHD	BALLEW	416A	08/27/93	93.30	-0.70	0.70
17	FRANKLIN	AHD	BALLEW	416A	08/27/93	94.80	0.80	0.80
18	FRANKLIN	AHD	BALLEW	416A	08/27/93	93.00	-1.00	1.00
19	FRANKLIN	AHD	BALLEW	416A	08/27/93	94.80	0.80	0.80
20	FRANKLIN	AHD	BALLEW	416A	08/26/93	93.20	-0.80	0.80
21	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.20	-1.80	1.80
22	FRANKLIN	AHD	BALLEW	416A	08/26/93	90.90	-3.10	3.10
23	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.50	-1.50	1.50
24	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.50	-1.50	1.50
25	FRANKLIN	AHD	BALLEW	416A	08/26/93	93.40	-0.60	0.60
26	FRANKLIN	AHD	BALLEW	416A	08/26/93	93.40	-0.60	0.60
27	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.60	-1.40	1.40
28	FRANKLIN	AHD	BALLEW	416A	08/26/93	91.90	-2.10	2.10
29	FRANKLIN	AHD	BALLEW	416A	08/26/93	91.60	-2.40	2.40
30	FRANKLIN	AHD	BALLEW	416A	08/26/93	93.30	-0.70	0.70
31	FRANKLIN	AHD	BALLEW	416A	08/26/93	94.70	0.70	0.70
32	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.90	-1.10	1.10
33	FRANKLIN	AHD	BALLEW	416A	08/26/93	92.80	-1.20	1.20
34	FRANKLIN	AHD	BALLEW	416A	08/25/93	92.30	-1.70	1.70
35	FRANKLIN	AHD	BALLEW	416A	08/25/93	93.00	-1.00	1.00
36	FRANKLIN	AHD	BALLEW	416A	08/25/93	93.40	-0.60	0.60
37	FRANKLIN	AHD	BALLEW	416A	08/25/93	92.70	-1.30	1.30
38	FRANKLIN	AHD	BALLEW	416A	08/25/93	89.00	-5.00	5.00
39	FRANKLIN	AHD	BALLEW	416A	08/25/93	95.10	1.10	1.10
40	FRANKLIN	AHD	BALLEW	416A	08/24/93	93.40	-0.60	0.60
41	FRANKLIN	AHD	BALLEW	416A	08/24/93	92.70	-1.30	1.30
42	FRANKLIN	AHD	BALLEW	416A	08/24/93	91.30	-2.70	2.70
43	FRANKLIN	AHD	BALLEW	416A	08/24/93	94.10	0.10	0.10
44	FRANKLIN	AHD	BALLEW	416A	08/24/93	92.00	-2.00	2.00

Figure A-2: Mat density individual project data base file.

Record#	DIVISION	COMPANY	PROJECT	PAY_ITEM	LOT	TONNAGE	PF_AC	PF_VOID	PF_MAT	PF_CRITI	YEAR
1	2	DUNN CONSTRUCT.	302-473-253-301	417	1	1452.29	1.02	1.02	0.00	1.02	1993
2	2	DUNN CONSTRUCT.	302-473-253-301	417	2	1524.61	1.02	1.02	0.00	1.02	1993
3	2	DUNN CONSTRUCT.	302-473-253-301	417	3	948.87	1.02	1.02	0.00	1.02	1993
4	2	DUNN CONSTRUCT.	302-473-253-301	417	4	1318.88	1.02	1.02	0.00	1.02	1993
5	2	DUNN CONSTRUCT.	302-473-253-301	417	5	55.04	1.00	1.00	0.00	1.00	1993
6	2	DUNN CONSTRUCT.	302-473-253-301	416	1	874.83	1.02	1.02	0.00	1.02	1993
7	2	DUNN CONSTRUCT.	302-473-253-301	416	2	1436.01	1.02	1.02	0.00	1.02	1993
8	2	DUNN CONSTRUCT.	302-473-253-301	416	3	303.44	1.00	1.00	0.00	1.00	1993
9	2	DUNN CONSTRUCT.	302-473-253-301	416	1	155.12	1.02	1.02	0.00	1.02	1993
10	2	DUNN CONSTRUCT.	302-473-253-301	416	2	285.94	1.02	1.02	0.00	1.02	1993
11	2	DUNN CONSTRUCT.	302-473-253-301	414	1	77.87	1.00	1.00	0.00	1.00	1993
12	2	DUNN CONSTRUCT.	302-473-253-301	414	1	1704.04	1.02	1.02	0.00	1.02	1993
13	2	DUNN CONSTRUCT.	302-473-253-301	414	2	50.86	1.00	1.00	0.00	1.00	1993
14	7	COUCH INC.	NHF-170(22)	327	1	2534.19	1.00	1.00	1.00	1.00	1993
15	7	COUCH INC.	NHF-170(22)	327	2	1760.02	1.00	1.00	1.00	1.00	1993
16	7	COUCH INC.	NHF-170(22)	327	3	2162.08	1.00	1.00	1.00	1.00	1993
17	7	COUCH INC.	NHF-170(22)	327	4	1917.28	1.00	1.00	1.00	1.00	1993
18	7	COUCH INC.	NHF-170(22)	327	5	639.23	1.00	1.00	1.00	1.00	1993
19	7	COUCH INC.	NHF-170(22)	327	6	186.39	1.00	1.00	1.00	1.00	1993
20	5	APAC-MISS	305-543-017-303	417	1	1515.80	1.02	1.02	1.02	1.02	1993
21	5	APAC-MISS	305-543-017-303	417	2	1702.91	1.02	1.00	1.01	1.00	1993
22	5	APAC-MISS	305-543-017-303	417	3	1019.90	1.02	1.02	1.02	1.02	1993
23	5	APAC-MISS	305-543-017-303	417	4	1897.01	1.02	1.02	1.02	1.02	1993
24	5	APAC-MISS	305-543-017-303	417	5	304.98	1.02	1.02	1.00	1.02	1993
25	5	APAC-MISS	305-543-017-303	416	7	53.31	1.02	1.02	0.00	1.02	1993
26	5	APAC-MISS	305-543-017-303	416	9	76.61	1.02	1.00	0.00	1.00	1993
27	5	APAC-MISS	305-543-017-303	416	10	76.36	1.02	1.00	0.00	1.00	1993
28	5	APAC-MISS	305-543-017-303	416	1	284.59	1.00	1.00	0.00	1.00	1993
29	5	APAC-MISS	305-543-017-303	416	2	253.90	1.02	1.02	0.00	1.02	1993
30	5	APAC-MISS	305-543-017-303	416	3	173.96	1.02	1.02	0.00	1.02	1993
31	5	APAC-MISS	305-543-017-303	416	4	192.80	1.02	1.02	0.00	1.02	1993
32	5	APAC-MISS	305-543-017-303	416	5	191.59	1.02	1.02	0.00	1.02	1993
33	5	APAC-MISS	305-543-017-303	416	6	228.00	1.02	1.02	0.00	1.02	1993
34	5	APAC-MISS	305-543-017-303	416	7	103.39	1.02	1.02	0.00	1.02	1993
35	5	APAC-MISS	305-543-017-303	416	8	75.85	1.02	1.02	0.00	1.02	1993
36	5	APAC-MISS	305-543-017-303	416	9	101.63	1.02	1.00	0.00	1.00	1993

Figure A-3: Pay factor data base file.

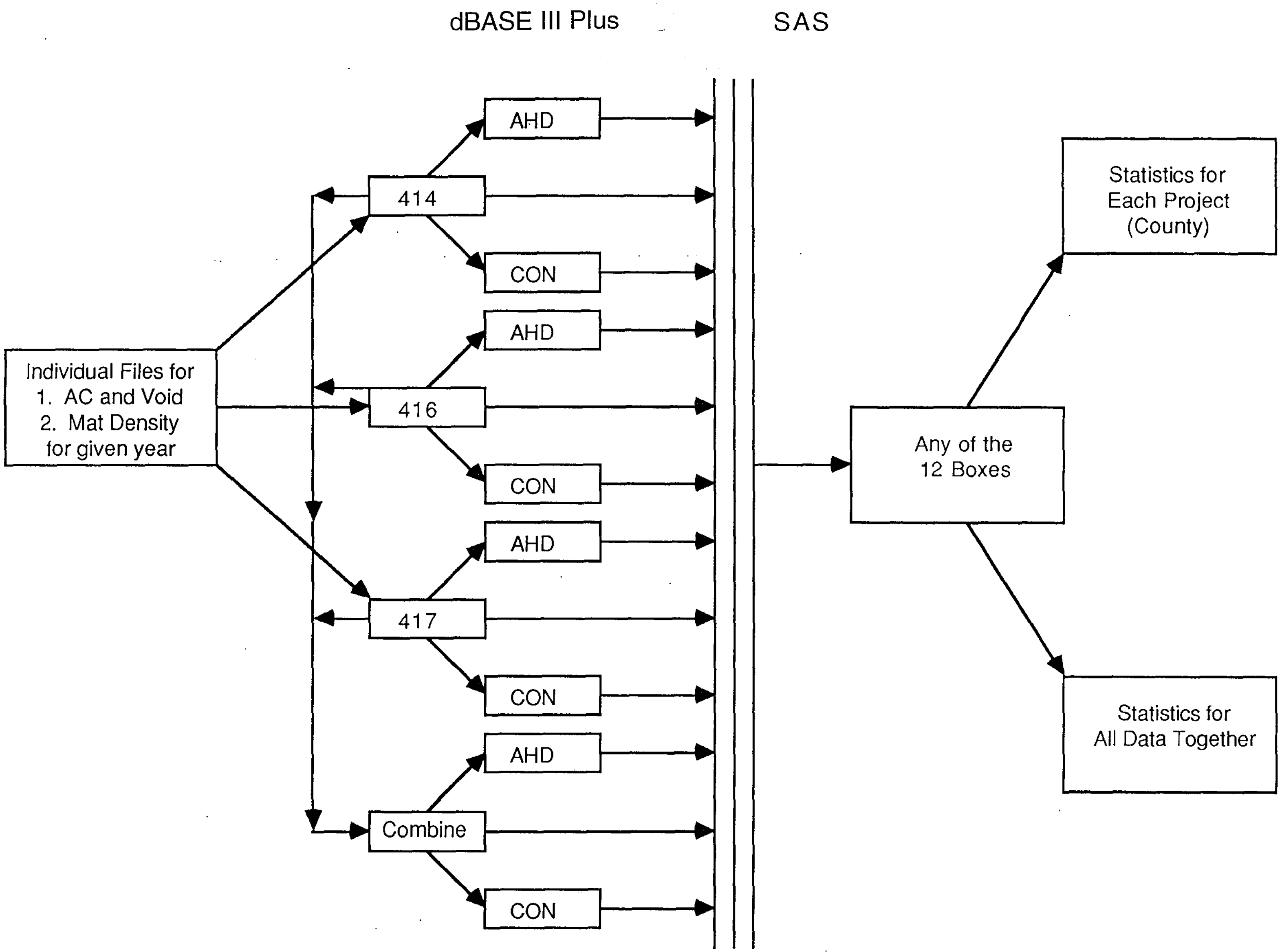

Figure A-4: Flow Chart - Primary Approach

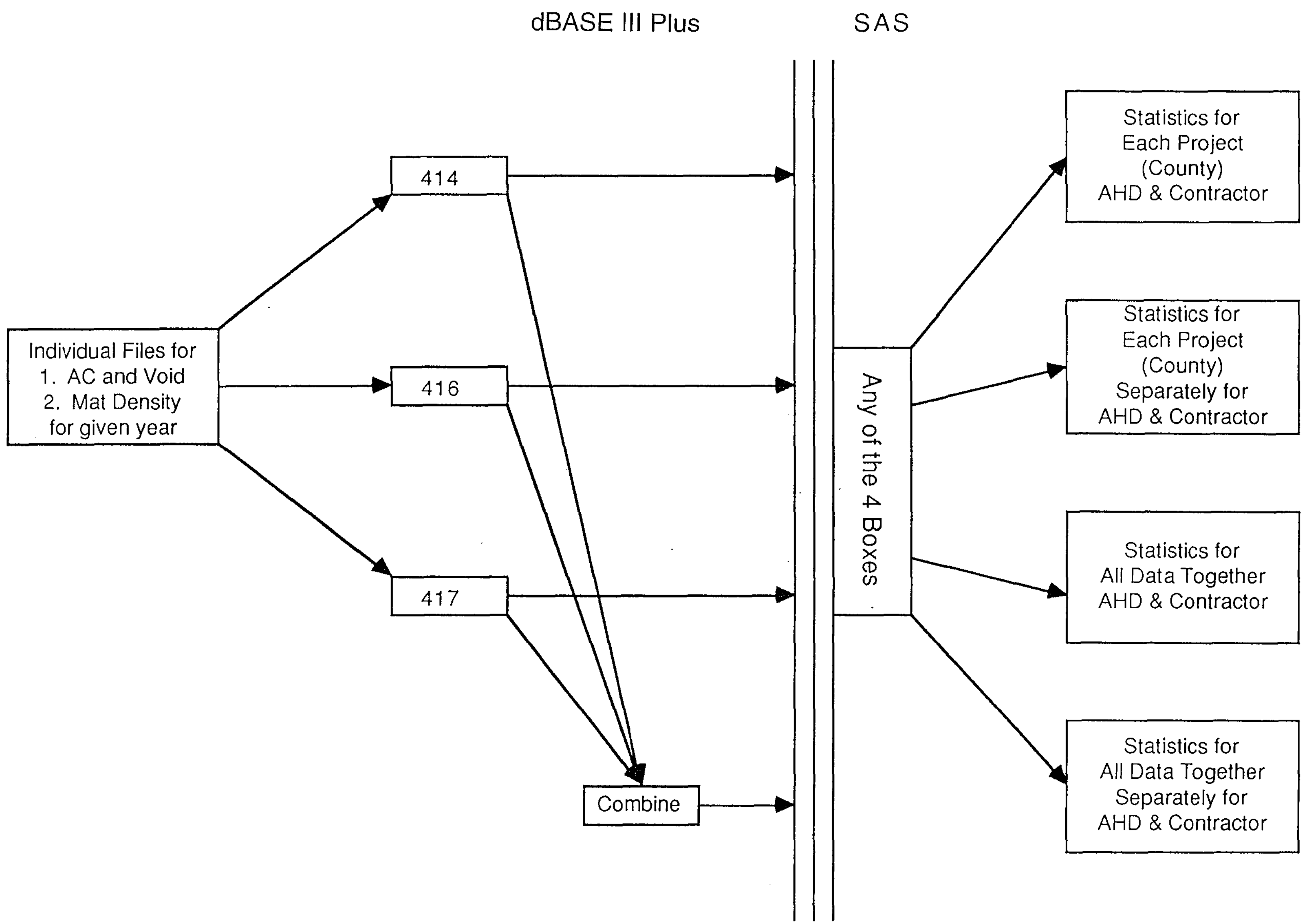

Figure A-5: Flow Chart - Primary Approach

AC ARITHMETIC DEVIATIONS STATISTICS FOR EACH PROJECT 1

9:45 Monday, April 25, 1994

Analysis Variable : ARI_DV_B

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLMAN	11	11	-0.4100000	0.1200000	-0.1336364	0.1824978
ETOWAH	67	67	-0.5600000	0.4400000	0.0528358	0.1845289
MARION	16	16	-0.4300000	0.2200000	-0.0162500	0.1632534
PICKENS	19	19	-0.4000000	0.2800000	-0.0200000	0.1937065
SHELBY1	43	43	-0.1700000	0.8200000	0.1695349	0.1704888
SHELBY2	13	13	-0.2300000	0.2000000	-0.0461538	0.1339489
WALKER1	28	28	-0.3500000	0.3100000	0.0139286	0.1628983
WALKER2	15	15	-0.3400000	-0.0200000	-0.1586667	0.1070959

Figure A-6: Output from program ACARIP.PGM for 1993 mix 417 dBASE file AV417.dbf.

AC ABSOLUTE DEVIATIONS STATISTICS FOR EACH PROJECT 2

9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_B

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLMAN	11	11	0.0500000	0.4100000	0.1827273	0.1273649
ETOWAH	67	67	0	0.5600000	0.1534328	0.1139584
MARION	16	16	0.0100000	0.4300000	0.1200000	0.1075794
PICKENS	19	19	0	0.4000000	0.1494737	0.1198366
SHELBY1	43	43	0	0.8200000	0.1844186	0.1538599
SHELBY2	13	13	0.0500000	0.2300000	0.1261538	0.0548541
WALKER1	28	28	0.0100000	0.3500000	0.1332143	0.0912893
WALKER2	15	15	0.0200000	0.3400000	0.1586667	0.1070959

Figure A-7: Output from program ACABSP.PGM for 1993 mix 417 dBASE file AV417.dbf.

AC ARITHMETIC DEVIATIONS STATISTICS FOR COMBINE DATA 3
9:45 Monday, April 25, 1994

Analysis Variable : ARI_DV_B

N Obs	N	Minimum	Maximum	Mean	Std Dev
212	212	-0.5600000	0.8200000	0.0289151	0.1926794

Figure A-8: Output from program ACARIC.PGM for 1993 mix 417 dBASE file AV417.dbf.

AC ABSOLUTE DEVIATIONS STATISTICS FOR COMBINE DATA 4
9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_B

N Obs	N	Minimum	Maximum	Mean	Std Dev
212	212	0	0.8200000	0.1543868	0.1183941

Figure A-9: Output from program ACABSC.PGM for 1993 mix 417 dBASE file AV417.dbf.

Analysis Variable : ARI_DV_V

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLMAN	11	11	-0.9900000	0.7700000	-0.2909091	0.5003290
ETOWAH	67	67	-1.2100000	0.9300000	-0.3988060	0.3963681
MARION	16	16	-0.7200000	0.5200000	-0.0318750	0.3524622
PICKENS	19	19	-0.8400000	0.7500000	-0.0652632	0.4435509
SHELBY1	43	43	-0.7600000	1.4500000	0.2874419	0.5242368
SHELBY2	13	13	-1.2400000	0.2400000	-0.3800000	0.4011234
WALKER1	28	28	-0.6400000	0.8400000	0.0639286	0.3115830
WALKER2	15	15	-0.6900000	0.6300000	-0.0640000	0.4358866

Figure A-10: Output from program VDARIP.PGM for 1993 mix 417 dBASE file AV417.dbf.

VOIDS ABSOLUTE DEVIATIONS STATISTICS FOR EACH PROJECT 6
9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_V

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLMAN	11	11	0.0400000	0.9900000	0.4927273	0.2763364
ETOWAH	67	67	0.0300000	1.2100000	0.4856716	0.2812700
MARION	16	16	0.0200000	0.7200000	0.2806250	0.2032558
PICKENS	19	19	0.0100000	0.8400000	0.3652632	0.2457724
SHELBY1	43	43	0	1.4500000	0.4572093	0.3813093
SHELBY2	13	13	0.0100000	1.2400000	0.4215385	0.3533140
WALKER1	28	28	0.0300000	0.8400000	0.2453571	0.1972117
WALKER2	15	15	0.0600000	0.6900000	0.3813333	0.1964276

Figure A-11: Output from program VDABSP.PGM for 1993 mix 417 dBASE file AV417.dbf.

VOIDS ARITHMATIC DEVIATIONS STATISTICS FOR COMBINE DATA 7
9:45 Monday, April 25, 1994

Analysis Variable : ARI_DV_V

N Obs	N	Minimum	Maximum	Mean	Std Dev
212	212	-1.2400000	1.4500000	-0.1104717	0.4951641

Figure A-12: Output from program VDARIC.PGM for 1993 mix 417 dBASE file AV417.dbf.

VOIDS ABSOLUTE DEVIATIONS STATISTICS FOR COMBINE DATA 8
9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_V

N Obs	N	Minimum	Maximum	Mean	Std Dev
212	212	0	1.4500000	0.4109434	0.2962676

Figure A-13: Output from program VDABSC.PGM for 1993 mix 417 dBASE file AV417.dbf.

MAT DENSITY ARITHMETIC DEVIATIONS STATISTICS FOR EACH PROJECT 9

9:45 Monday, April 25, 1994

Analysis Variable : ARI_DV_N

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLLMAN	59	59	-1.7000000	1.4000000	-0.3118644	0.8162329
ETOWAH	340	340	-5.5000000	3.7000000	-0.5252941	1.5338679
PICKENS	94	94	-3.3000000	1.8000000	-0.9351064	0.9102413
SHELBY	311	311	-1.7000000	2.2000000	0.0913183	0.6749111
WALKER1	105	105	-4.7000000	3.3000000	-1.2933333	1.5023870
WALKER2	73	73	-4.5000000	2.0000000	-1.1671233	1.3621934

Figure A-14: Output from program MDARIP.PGM for 1993 mix 417 dBASE file AV417.dbf.

MAT DENSITY ABSOLUTE DEVIATIONS STATISTICS FOR EACH PROJECT 10

9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_N

COUNTY	N Obs	N	Minimum	Maximum	Mean	Std Dev
CULLLMAN	59	59	0.1000000	1.7000000	0.7355932	0.4634067
ETOWAH	340	340	0	5.5000000	1.2594118	1.0191672
PICKENS	94	94	0	3.3000000	1.0797872	0.7306765
SHELBY	311	311	0	2.2000000	0.5614148	0.3842755
WALKER1	105	105	0.1000000	4.7000000	1.6685714	1.0653922
WALKER2	73	73	0	4.5000000	1.4602740	1.0366532

Figure A-15: Output from program MDABSP.PGM for 1993 mix 417 dBASE file AV417.dbf.

MAT DENSITY ARITHMETIC DEVIATIONS STATISTICS FOR COMBINE DATA 11
9:45 Monday, April 25, 1994

Analysis Variable : ARI_DV_N

N Obs	N	Minimum	Maximum	Mean	Std Dev
982	982	-5.5000000	3.7000000	-0.4862525	1.2969282

Figure A-16: Output from program MDARIC.PGM for 1993 mix 417 dBASE file AV417.dbf.

MAT DENSITY ABSOLUTE DEVIATIONS STATISTICS FOR COMBINE DATA 12
9:45 Monday, April 25, 1994

Analysis Variable : ABS_DV_N

N Obs	N	Minimum	Maximum	Mean	Std Dev
982	982	0	5.5000000	1.0483707	0.9047121

Figure A-17: Output from program MDABSC.PGM for 1993 mix 417 dBASE file AV417.dbf.

```
Title 'AC ARITHMETIC DEVIATIONS STATISTICS FOR EACH PROJECT';
libname out 'c:\';
filename db36 'a:\XXXXX.dbf';
options linesize=80
        pagesize=60;
proc DBF db3 = db36
         out = out.convert6;
run;

data out.convert6;
set out.convert6;

if BITCON = 0 then
   ARI_DV_B = .;

proc MEANS;
class county;
var ari_dv_b;
run;
```

Figure A-18: Text of program ACARIP.PGM.

ALL PAY FACTORS ANALYSIS FOR INDIVIDUAL DIVISION 1

10:10 Monday, April 25, 1994

DIVISION	N Obs	Variable	N	Minimum	Maximum	Mean
2	13	PF_CRITI	13	1.0000000	1.0200000	1.0138462
		PF_AC	13	1.0000000	1.0200000	1.0138462
		PF_VOID	13	1.0000000	1.0200000	1.0138462
		PF_MAT	0	.	.	.
5	17	PF_CRITI	17	1.0000000	1.0200000	1.0141176
		PF_AC	17	1.0000000	1.0200000	1.0188235
		PF_VOID	17	1.0000000	1.0200000	1.0141176
		PF_MAT	5	1.0000000	1.0200000	1.0140000
7	6	PF_CRITI	6	1.0000000	1.0000000	1.0000000
		PF_AC	6	1.0000000	1.0000000	1.0000000
		PF_VOID	6	1.0000000	1.0000000	1.0000000
		PF_MAT	6	1.0000000	1.0000000	1.0000000

DIVISION	N Obs	Variable	Std Dev
2	13	PF_CRITI	0.0096077
		PF_AC	0.0096077
		PF_VOID	0.0096077
		PF_MAT	.
5	17	PF_CRITI	0.0093934
		PF_AC	0.0048507
		PF_VOID	0.0093934
		PF_MAT	0.0089443
7	6	PF_CRITI	0
		PF_AC	0
		PF_VOID	0
		PF_MAT	0

Figure A-19: Output from program PFDIV.PGM for a part of 1993 pay factor dBASE file PF93.dbf.

COMPANY	N Obs	Variable	N	Minimum	Maximum
APAC-MISS	17	PF_CRITI	17	1.0000000	1.0200000
		PF_AC	17	1.0000000	1.0200000
		PF_VOID	17	1.0000000	1.0200000
		PF_MAT	5	1.0000000	1.0200000
COUCH INC.	6	PF_CRITI	6	1.0000000	1.0000000
		PF_AC	6	1.0000000	1.0000000
		PF_VOID	6	1.0000000	1.0000000
		PF_MAT	6	1.0000000	1.0000000
DUNN CONSTRUCT.	13	PF_CRITI	13	1.0000000	1.0200000
		PF_AC	13	1.0000000	1.0200000
		PF_VOID	13	1.0000000	1.0200000
		PF_MAT	0	.	.

COMPANY	N Obs	Variable	Mean	Std Dev
APAC-MISS	17	PF_CRITI	1.0141176	0.0093934
		PF_AC	1.0188235	0.0048507
		PF_VOID	1.0141176	0.0093934
		PF_MAT	1.0140000	0.0089443
COUCH INC.	6	PF_CRITI	1.0000000	0
		PF_AC	1.0000000	0
		PF_VOID	1.0000000	0
		PF_MAT	1.0000000	0
DUNN CONSTRUCT.	13	PF_CRITI	1.0138462	0.0096077
		PF_AC	1.0138462	0.0096077
		PF_VOID	1.0138462	0.0096077
		PF_MAT	.	.

Figure A-20: Output from program PFCOM.PGM for a part of 1993 pay factor dBASE file PF93.dbf.

PROJECT	N Obs	Variable	N	Minimum	Maximum
302-473-253-301	13	PF_CRITI	13	1.0000000	1.0200000
		PF_AC	13	1.0000000	1.0200000
		PF_VOID	13	1.0000000	1.0200000
		PF_MAT	0	.	.
305-543-017-303	17	PF_CRITI	17	1.0000000	1.0200000
		PF_AC	17	1.0000000	1.0200000
		PF_VOID	17	1.0000000	1.0200000
		PF_MAT	5	1.0000000	1.0200000
NHF-170(22)	6	PF_CRITI	6	1.0000000	1.0000000
		PF_AC	6	1.0000000	1.0000000
		PF_VOID	6	1.0000000	1.0000000
		PF_MAT	6	1.0000000	1.0000000

PROJECT	N Obs	Variable	Mean	Std Dev
302-473-253-301	13	PF_CRITI	1.0138462	0.0096077
		PF_AC	1.0138462	0.0096077
		PF_VOID	1.0138462	0.0096077
		PF_MAT	.	.
305-543-017-303	17	PF_CRITI	1.0141176	0.0093934
		PF_AC	1.0188235	0.0048507
		PF_VOID	1.0141176	0.0093934
		PF_MAT	1.0140000	0.0089443
NHF-170(22)	6	PF_CRITI	1.0000000	0
		PF_AC	1.0000000	0
		PF_VOID	1.0000000	0
		PF_MAT	1.0000000	0

Figure A-21: Output from program PFPRJ.PGM for a part of 1993 pay factor dBASE file PF93.dbf.

```
Title 'ALL PAY FACTORS ANALYSIS FOR INDIVIDUAL DIVISION';
libname out 'c:\';
filename db36 'a:\XXXX.dbf';
options linesize=76
        pagesize=58;
proc DBF db3 = db36
         out = out.convert6;
run;

data out.convert6;
set out.convert6;
if PF_AC = 0 then
   PF_AC = .;

if PF_VOID = 0 then
   PF_VOID = .;

if PF_MAT = 0 then
   PF_MAT = .;

if PF_CRITI = 0 then
   PF_CRITI = .;
run;

proc MEANS;
class division;
var pf_criti pf_ac pf_void pf_mat;
run;
```

Figure A-22: Text of program PFDIV.PGM.