INTERIM REPORT NO. 1

QUALITY ASSURANCE PROGRAM
(Bituminous Concrete and Central Mix Aggregates)

by

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Senior Research Scientist

Virginia Highway and Transportation Research Council
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SUMMARY

This report presents the results of a pilot quality assurance program initiated in the Richmond District in 1978. Under this program the producer's control tests are used for the acceptance of central mix aggregate and bituminous concrete and the Department is thus enabled to reduce its testing. The program has proven to be successful and has been extended statewide with the participation of the producers being on a voluntary basis.

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INTRODUCTION

Virginia has used statistically oriented specifications for bituminous concrete and central mix aggregates since the late 1960's. While these specifications have worked very well and have served as models for other states, the Virginia Department of Highways and Transportation is always looking for ways to upgrade their specifications and procedures.

In the 1970's, on the national scene statistically oriented specifications grew into quality assurance specifications. The difference between these types of specifications is very subtle and often goes unrecognized. In the author's terminology the statistically oriented specifications must require random sampling, a single point of acceptance, a single acceptance test method, and statistically derived tolerances based on a stated lot size that includes more than one sample by the buyer, in this case the Department. Little or nothing is required in writing of the producer. The statistically oriented specifications were, for the most part, based only on Department acceptance tests.

With the evolution of the statistically oriented specifications into quality assurance specifications, the increased importance of control tests by the producer has become apparent, though the Department retains a strong role in product acceptance. One criticism of this system has been the duplication of tests by the producer and the Department. Although duplication is certainly undesirable, the increased emphasis on the producer's control testing is important because the intent, even more clearly than it was under statistically oriented specifications, is for the producer to control his product. If producer control is given primary emphasis, and is effective, then it follows that Department acceptance tests can be deemphasized.

This is the philosophy underlying Virginia's latest quality assurance program. As an incentive to the producer, and to allow the Department to reduce its testing and thus its personnel requirements, the system was modified still further as discussed below.

NEW QUALITY ASSURANCE PROGRAM

Since control tests must be run by the producer, and in implementing this phase of the program a definite minimum testing program had to be devised, the least disruptive approach appeared to be to ask the producer to follow the very same testing program that had been conducted by the Department. And because this program includes the acceptance procedures stipulated in the statistically oriented specifications, the acceptance tests prescribed by the specifications are used to determine payment to the producer. The difference in the present program, of course, is that the producer performs the acceptance tests. It may seen ridiculous to many people that the producer tests his own product to determine if any price adjustments are warranted. However, thinking positively about this system, if the producer is conscientious in running his control (acceptance) tests, the Department can greatly reduce its testing.

Production Tests

Production tests are control tests run by the producer and used for determining acceptance and thus price adjustments. The lot size is 2,000 tons and four tests are taken per lot. The sampling rate is thus one sample per 500 tons of material produced per job mix formula, taken in a random manner.

In addition to determining the average of each lot and the standard deviation of the production, the producer must maintain control charts. The tolerances and implied standard deviations are shown in Tables 1 and 2, respectively, for central mix aggregate and bituminous concrete. These are the same limits used in the statistically oriented specifications.

Table 1. Aggregate Base— Standard Deviations Implied by Specified Tolerances for Means

(For sample size of 4 and 99.7% confidence level)

Sieve (or Cement Content)	Specified Tolerance for Mean of 4 Samples, percent	Implied Standard Deviation, percent
1"	±5.0	3.33
3/8"	±9.5	6.33
#10	±7.0	4.67
#40	±4.0	2.67
#200	±2.0	1.33
Cement Content	±0.8	0.53

Table 2. Bituminous Concrete— Standard Deviations Implied by Specified Tolerances for Means

(For sample size of 4 and 99.7% confidence level)

Sieve or Asphalt Content	Specified Tolerance for Mean of 4 Samples, percent	Implied Standard Deviation, percent
3/4"	±5.0	3.33
3/8"	±5.0	3.33
#4	±5.0	3.33
#8	±4.5	3.00
#30	±4.0	2.67
#50	±2.5	1.67
#200	±1.5	1.00
Asphalt Content	±0.4	0.27

Monitor Tests

Samples for monitor tests are taken by the Department and the tests are run at the District Materials Laboratory for the sole purpose of verifying the accuracy of the production tests.

During the first week of production, four monitor tests are made; therefore, two tests per week are made. Samples for these tests are taken in a random time procedure.

Statistical Tests

Two statistical comparisons are made between the results of the production tests and those from the monitor tests.

1. The 'F' test is used to determine if the variability, σ_m, as measured by the monitor tests exceeds the variability, σ_p, as measured by the production tests.

2. The 't' test is used to determine if the mean, $\overline{X}_m$, as determined by the monitor tests differs from the mean, $\overline{X}_p$, as determined from the production tests.

If either of the statistical comparisons indicates the monitor test results are not in agreement with those from the production tests, the production test results are then compared to the specification as shown in Tables 1 and 2. If the monitor results indicate compliance with the specifications, even though they do not agree statistically with the production test results, no action is taken. However, if the monitor results do not show compliance with the specification limits, the Department may place an inspector in the plant to observe the production tests to try to determine the source of the differences.

Procedure for Determining if σ_m is Significantly Larger Than σ_p

The steps to determine if σ_m exceeds σ_p at a significance level of 1% are listed below.

1. Determine n_m and n_p,

   where

   n_m = the number of monitor tests, and

   n_p = the number of production tests.

2. Look up $F_{.99}$, the F value that would be exceeded only with a 99% level of confidence, in Table 3, column n_c^{-1}, row n_m^{-1}.

3. Square the standard deviations determined for production and monitoring test data; i.e., compute σ_m^2 and σ_p^2.

4. Compute $F = \dfrac{\sigma_m^2}{\sigma_p^2}$.

5. If $F > F_{.99}$, conclude that σ_m exceeds σ_p; otherwise conclude that σ_m is not larger than σ_p.

Procedure for Determining if $\overline{X}_m$ Differs from $\overline{X}_p$ Significantly

Listed below are the procedural steps for determining if $\overline{X}_m$ differs from $\overline{X}_p$ at a 1% significance level.

1. Determine n_m and n_p as above.

2. Compute σ_m^2 and σ_p^2 as above.

3. Compute V_m and V_p,

   where

$$V_m = \frac{\sigma_m^2}{n_m} \text{, and}$$

$$V_p = \frac{\sigma_p^2}{n_p} .$$

4. Compute df,

   where

$$df = \frac{(V_m + V_p)^2}{\frac{V_m^2}{n_m+1} + \frac{V_p^2}{n_p+1}} -1,$$

   and round df to the nearest integer value.

5. Look up $t_{1-\alpha/2}$ or $t_{0.995}$, since testing is done at a 1% significance level ($\alpha = 0.01$), in Table 4 for the rounded value of df computed in step 4.

6. Compute $\mu = t_{0.995}\sqrt{V_m + V_p}$

7. If $\bar{X}_m - \bar{X}_p > \mu$, conclude that $\bar{X}_m$ differs from $\bar{X}_p$; otherwise conclude that there is no reason to believe $\bar{X}_m$ differs from $\bar{X}_p$.

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TABLE 3

Table of Percentiles of the F Distribution

$\alpha = 1\%$

n_m-1 / n_c-1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	4052	4999.5	5403	5625	5764	5859	5928	5982	6022	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23	27.05	26.87	26.69	26.60	26.50	26.41	26.32	26.22	26.13
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

TABLE 4

Percentiles of the t Distribution

*

df	$t_{.60}$	$t_{.70}$	$t_{.80}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$
1	.325	.727	1.376	3.078	6.314	12.706	31.821	63.657
2	.289	.617	1.061	1.886	2.920	4.303	6.965	9.925
3	.277	.584	.978	1.638	2.353	3.182	4.541	5.841
4	.271	.569	.941	1.533	2.132	2.776	3.747	4.604
5	.267	.559	.920	1.476	2.015	2.571	3.365	4.032
6	.265	.553	.906	1.440	1.943	2.447	3.143	3.707
7	.263	.549	.896	1.415	1.895	2.365	2.998	3.499
8	.262	.546	.889	1.397	1.860	2.306	2.896	3.355
9	.261	.543	.883	1.383	1.833	2.262	2.821	3.250
10	.260	.542	.879	1.372	1.812	2.228	2.764	3.169
11	.260	.540	.876	1.363	1.796	2.201	2.718	3.106
12	.259	.539	.873	1.356	1.782	2.179	2.681	3.055
13	.259	.538	.870	1.350	1.771	2.160	2.650	3.012
14	.258	.537	.868	1.345	1.761	2.145	2.624	2.977
15	.258	.536	.866	1.341	1.753	2.131	2.602	2.947
16	.258	.535	.865	1.337	1.746	2.120	2.583	2.921
17	.257	.534	.863	1.333	1.740	2.110	2.567	2.898
18	.257	.534	.862	1.330	1.734	2.101	2.552	2.878
19	.257	.533	.861	1.328	1.729	2.093	2.539	2.861
20	.257	.533	.860	1.325	1.725	2.086	2.528	2.845
21	.257	.532	.859	1.323	1.721	2.080	2.518	2.831
22	.256	.532	.858	1.321	1.717	2.074	2.508	2.819
23	.256	.532	.858	1.319	1.714	2.069	2.500	2.807
24	.256	.531	.857	1.318	1.711	2.064	2.492	2.797
25	.256	.531	.856	1.316	1.708	2.060	2.485	2.787
26	.256	.531	.856	1.315	1.706	2.056	2.479	2.779
27	.256	.531	.855	1.314	1.703	2.052	2.473	2.771
28	.256	.530	.855	1.313	1.701	2.048	2.467	2.763
29	.256	.530	.854	1.311	1.699	2.045	2.462	2.756
30	.256	.530	.854	1.310	1.697	2.042	2.457	2.750
40	.255	.529	.851	1.303	1.684	2.021	2.423	2.704
60	.254	.527	.848	1.296	1.671	2.000	2.390	2.660
120	.254	.526	.845	1.289	1.658	1.980	2.358	2.617
∞	.253	.524	.842	1.282	1.645	1.960	2.326	2.576

Printout

A typical printout for a bituminous concrete job mix is shown in Figure 1. The identification is shown at the top along with the production dates the tests include and the date the computer ran the data. The next series of data describe the production test results including the number of tests, the mean, and the standard deviation for each sieve and asphalt content. The next series of data summarize the monitor tests with the same type data as given for the production tests. The F test results are shown next. If, as on the 1/2" sieve and asphalt content values in this case, a result exceeds the F_{99} value, the computer places four stars under that value that does not fall within the statistical limits. The results of the t test are shown next, and again if a statistical difference is found, that result is starred. The next data shown are the job mix, so that the production and monitor tests can be compared to what the producer had indicated would be produced. Only when the F or t tests indicate a significant difference are the individual production and monitor test results printed out. This printout allows a visual check as to why a statistical difference occurred. Often when the F test indicates a significant difference, the difference is due to a single test being extremely high or low.

PILOT STUDY RESULTS

A pilot study was begun in the Richmond District in the spring of 1978. Several changes were made in the program over the nearly two-year period in which it was conducted. One major change was to take the monitor sample from a production sample, simply by taking a large size sample and splitting it. This greatly improved the relationship between the two results. However, this procedure does require an adjustment in the random method of taking the production sample. This adjustment is accomplished by having the split sample serve as the subsequently scheduled random production sample by taking the sample with the monitor sample.

The results analyzed here were taken from the most recent reports produced from the pilot study; these are dated either late 1979 or early 1980. Only those printouts including three or more monitor test results were analyzed. The results are shown in Tables 5 and 6 for central mix aggregates and bituminous concrete, respectively.

BITUMINOUS CONCRETE
COMPARISON
PRODUCTION AND MONITOR TESTS

PLANT # 413 SHOOSMITH BROTHERS INC
CHESTER VA

BEG.DATE=790720
END DATE=790927
RUN DATE=11-21-79

MIX TYPE 5 S-5
JOB MIX ID 879

PER CENT PASSING SIEVE SIZE

	1/2	#4	#30	#200	ASPH
PROD.					
N	20	20	20	20	20
MEAN	100.0	63.8	28.3	4.6	6.1
S.D.	0.0	1.7	1.2	0.4	0.1
MONT.					
N	3	3	3	3	3
MEAN	99.7	65.4	31.2	5.2	6.1
S.D.	0.5	3.9	2.5	0.6	0.3
F	999.99	5.62	4.39	2.56	17.74
F.99	5.93 ****	5.93	5.93	5.93	5.93 ****
AM-AC	-0.3	1.6	2.9	0.7	0.1
HU	2.7	22.7	14.6	3.5	1.9
JOBMIX DATA	100.0	64.0	27.0	4.5	6.0

PRODUCTION =

DATE	LOT					
790720	21	100.0	64.6	28.4	5.5	5.9
790723	21	100.0	66.1	27.3	4.5	6.0
790726	21	100.0	64.6	28.6	4.5	6.0
790727	21	100.0	61.4	30.2	5.0	6.0
790803	22	100.0	60.7	28.7	4.4	6.2
790806	22	100.0	64.9	28.5	4.6	6.1
790807	22	100.0	63.5	28.2	4.3	6.1
790807	22	100.0	65.3	27.9	4.5	6.1
790809	23	100.0	61.4	28.3	4.8	6.2
790810	23	100.0	65.5	30.0	4.4	5.9
790814	23	100.0	63.2	27.7	4.1	6.1
790814	23	100.0	62.9	27.3	4.6	6.1
790815	24	100.0	61.7	24.9	4.6	6.1
790827	24	100.0	61.8	30.4	5.1	6.0
790917	24	100.0	64.9	27.5	3.8	6.0
790918	24	100.0	63.9	28.3	4.2	6.1
790918	25	100.0	65.4	28.6	4.7	6.1
790920	25	100.0	64.4	27.7	4.6	6.1
790927	25	100.0	64.1	28.7	4.6	6.1
790927	25	100.0	65.7	29.0	4.8	6.0

MONITOR

DATE	LOT					
790709	19	100.0	63.8	28.6	5.9	5.8
790809	23	99.2	62.6	31.3	4.8	6.2
790918	25	100.0	69.9	33.6	5.0	6.5

Figure 1. Typical computer printout.

Table 5

Pilot Study Results - Central Mix Aggregates

Plant	Date	n_p/n_m	Comments
Burkeville Stone	1-17-80	25/8	No differences (11-23-79 29/7 $\overline{X}_m$ high on #200)
General C. S.	1-17-80	37/4	No differences (1-2-80 21/3 $\overline{X}_m$ low on 3/8")
General C. S. (w/c)	1-17-80	52/12	No differences
Rockville Stone	11-23-79	9/3	No differences (8-14-79 32/10 σ_m high on 1")
Lone Star	1-17-80	31/9	σ_m high on 1" & 3/8"; $\overline{X}_m$ high on #200
Lone Star	1-2-80	28/5	No differences
Lone Star	1-24-80	79/13	σ_m high on 1" & 3/8"
Vulcan Materials	1-2-80	32/8	σ_m high on 3/8"
Royal Stone	9-26-79	12/5	No differences
Royal Stone (w/c)	9-21-79	29/6	No differences
Tidewater Quarries	1-17-80	38/6	σ_m high on #10, #40, and #200
Richmond C. S.	1-17-80	10/4	No differences (1-2-80 18/5 σ_m high on #40 & #200
Mega	10-25-79	30/3	No differences
Mega	1-17-80	44/8	$\overline{X}_m$ low on #200

Table 6

Pilot Study Results - Bituminous Concrete

Plant	Mix	Date	n_p/n_m	Comments
E. G. Bowles	B-3	12-1-78*	31/7	σ_m high on 3/4"
Lee-Hy	I-2	10-25-79	32/10	σ_m high on 3/8" & AC%
Lee-Hy	S-5	12-1-78*	22/6	σ_m high on #4
Lee-Hy	I-2	12-1-78*	17/7	σ_m high on 3/8", #200 & AC%
Shoosmith Bros.	S-5	11-21-79	20/3	σ_m high on AC%
Short Paving	I-2	7-5-79	21/6	σ_m high on AC%
Short Paving	S-5	8-1-79	12/3	No differences
Mega	I-2	8-1-79	24/3	$\overline{X}_m$ low on AC%
Mega	S-5	7-5-79	21/4	No differences

*Tested prior to splitting monitor sample

Of the 14 aggregate plants for which up-to-date data were available, 9 had no significant differences on the most recent printout. Whenever possible the last data showing a significant difference were located and are shown under comments. The standard deviations tend to differ more often than do the means. Three of the 14 plants appear to have had significant differences on more than one sieve. Only 2 plants that had significant differences produced material that the monitor tests indicated was out of specifications, and for one of these the difference was due to a single test result being exceptionally high.

Of the 9 asphalt plants included in the pilot study, 2 had no significant differences. In 6 of the 7 plants for which a significant difference was indicated, the standard deviations from the monitor tests were higher than those from the production tests. Also, of the 7 plants in which a significant difference was indicated, 5 were out of specification. However, as Table 6 shows, 2 of these were shown to be out of specification by results of tests taken prior to implementation of the procedure of splitting the monitor sample from the production sample.

One of the important aspects of the pilot study was to determine if duplication of testing could be reduced. In the aggregate industry particularly, control tests are a standard procedure and thus the Department's acceptance tests were often a duplication of effort. Having the producer supplement his normal control tests by the specified production test allowed the Department to substantially reduce its testing load. As a consequence, the district was able to reduce personnel by eight inspectors. This provides a annual monetary savings of more than $100,000 in salaries in this one district. Based on these potential monetary savings and no apparent loss in efficiency, the task force appointed to monitor the pilot program recommended that the program be expanded statewide on a voluntary basis for the same materials. This recommendation was implemented and workshops were held in six districts in the spring of 1980 to apprise both contractors and Department personnel of the program.

It is still too soon to tell how widespread the voluntary acceptance will be, but as experience is gained with the program it will be detailed in additional reports.