2017

FINAL REPORT

REVIEW OF A BITUMINOUS CONCRETE STATISTICAL SPECIFICATION

by

S. N. Runkle, Highway Research Analyst
and
C. S. Hughes, Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

May 1971
VHRC 70-R43

SUMMARY

The statistically oriented specification for bituminous concrete production reviewed in this report was used as a basis for acceptance of more than one million tons of bituminous concrete in 1970. Data obtained from this system were analyzed for gradation and asphalt content for such comparisons as how well the production average matched the stated job mix formula; how well the variability of lot means matched the variability measure the limits were based on; and how well the range method of predicting the standard deviation matched the actual standard deviation.

It was found that the 1970 bituminous concrete production was consistent with that of 1967, on which the specification was based; that the range method can predict standard deviations accurately and can be used on a lot by lot basis; and that, although the present tolerances are working well, there are some areas where improvements are possible.

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INTRODUCTION

The Virginia Highway Research Council has been working in the area of the application of statistical specifications to highway operations since the spring of 1964. This work initially led to the density requirements now employed for the majority of flexible pavements built on the primary and interstate systems. For the past few years, the Council's Bituminous Section has been developing and field testing a statistically oriented acceptance plan to replace the conventional system for controlling the production of bituminous concrete.[1, 2, 3] This statistical plan, in the form of a specification (Appendix A), has now been used as a basis for acceptance of more than one million tons of bituminous concrete.

In this specification, there are two basic areas that involve statistics. One is a tolerance on the amount the average of four samples may vary from the job mix; the other is a limit on the variability of all individual tests. Both of these requirements pertain to all sieves in the gradation analysis and to asphalt content, and they are all that are needed to establish the distribution of the product.

PURPOSE AND SCOPE

The purpose of this study was to review the data obtained from the statistically oriented system now being used for the acceptance of bituminous concrete, and to recommend any revisions thought to be needed.

The mix data were received on Form TL-100 (Appendix B) and allowed the following comparisons:

1. Job mix formula (JM) vs. production average ($\bar{X}$). This analysis predicts how well the product matches what the contractor has said he will produce.

2. Variability of lot means vs. statistical limits. This analysis determines if the variability of the lot means is significantly greater or less than the variability measure the limits were based on.

3. Total standard deviation (S) vs. total standard deviation limits. This analysis determines if a significant difference exists between the total standard deviation and that on which the limits are based.

4. Standard deviation vs. range method of estimating standard deviation. The present specification accepts variability based on the standard deviation of the entire project. Another method of variability acceptance is the range method, which can be used easily on a lot by lot basis. This analysis determines how well the range can estimate the standard deviation.

5. Standard deviation vs. length of operation. This analysis should indicate whether the variability of a plant remains constant, or increases or decreases with time.

6. Standard deviation of batch plants vs. continuous plants. This analysis should indicate whether one type of plant is consistently more or less variable than the other type. (Note: The working plan indicated that this analysis would be conducted between plants of the same type. Because of the lack of descriptive data on the TL-100 forms, this was not possible.)

7. Variability between truck quadrants (Appendix C) within a project. This analysis should indicate the adequacy of mixing and the occurrence of segregation.

ANALYSIS AND RESULTS

Because the statistical specifications were used on only a relatively few 1969 projects, these projects were used only to establish the type and number of analyses to be included in the study. The analyses established were then used on the data from 1970 projects. The analyses were made on the following number and types of bituminous concrete mixes:

1. 32 base course mixes (B-3).

2. 39 intermediate mixes (10 I-2 and 29 MI-2*).

3. 49 surface mixes (38 S-5 and 11 MS-5*).

For simplicity, the terms I-2 and S-5 will be used for intermediate and surface mixes for the remainder of this report.

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*Note: The MI-2 and I-2 mixes differ only in that the former does not use the $\frac{3}{8}$" and No. 8 sieves for acceptance. Likewise, the MS-5 differs from the S-5 mix in that the $\frac{3}{8}$", No. 4, and No. 50 sieves are not used for acceptance of the former.

Overall Production Characteristics

Table I shows a summary of the tolerances and production characteristics for the 1967 data from which the tolerances were derived, as well as the 1970 data used in the analysis.

The ability of a plant to remain within the process tolerances for each sieve and asphalt content is based on two characteristics:

1. Ability to "hit" the job mix. This is measured by taking the difference between the job mix and the production average.

2. Production variability. This is simply the production standard deviation, which is numerically equivalent to two standard errors since the sample size per lot is four.

When these two characteristics are combined, the total is best described in Figure 1, using the 1970 I-2, $\frac{3}{8}$" sieve data. The tolerance for this sieve is 5.5% measured from the job mix. The data indicated that the production average missed the job mix by 1.82% and the measured standard deviation (or two standard errors) equalled 3.30% for a total value of 5.12%.

As long as the sum of the combined values for a majority of the projects is close to the tolerance, the tolerances can be considered satisfactory; however, when the combined value consistently exceeds the tolerance, then the tolerance should be increased; conversely, if the total variability does not consistently approach the tolerance, then the tolerance should be decreased.

The first trend noticeable from Table I is the consistency between the 1967 and 1970 data, particularly in the total columns. The other trend is the apparent lack of consistency in the magnitude of the mix total variability in comparison to the tolerances. This item will be discussed in more detail in the following sections.

The first three comparisons listed under Purpose and Scope determine the overall production characteristics of the particular project under scrutiny and will be discussed separately, but summarized together. The data are given in Tables II, III and IV for B-3, I-2, and S-5 mixes, respectively. In addition to the data for each project, the grand average, tolerances, and percent above the tolerance are given.

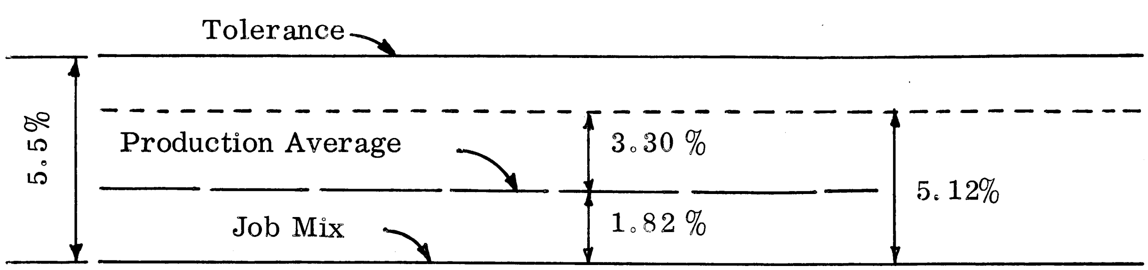

Figure 1. Diagram indicating concept of total variability value.

TABLE I

SUMMARY

AVERAGE STANDARD DEVIATIONS AND JOB MIX
LESS PRODUCTION AVERAGE DIFFERENCES
1967* and 1970

				1967						1970								
	Tolerance			I-2			S-5			B-3			I-2			S-5		
Sieve Size	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total
$\frac{3}{4}$	2.0	3.5	5.5	2.63	0.79	3.42				1.39	2.75	4.14						
$\frac{1}{2}$	2.0	3.5	5.5															
$\frac{3}{8}$	2.0	3.5	5.5	1.09	3.10	4.19	2.95	1.54	4.49				1.82	3.30	5.12	1.57	1.37	2.94
No. 4	1.5	3.0	4.5	2.49	3.09	5.58	2.35	2.90	5.25	1.85	2.91	4.76	1.50	2.68	4.18	2.02	2.90	4.92
No. 8	1.5	3.0	4.5	1.67	2.68	4.35	1.49	2.89	4.38	1.26	2.53	3.79	1.94	2.20	4.14	1.29	2.79	4.08
No. 30	1.5	3.0	4.5				1.18	1.74	2.92							1.37	1.87	3.24
No. 50	1.0	2.0	3.0	0.75	1.29	2.04	1.60	1.39	2.99				1.10	1.15	2.25	0.82	1.31	2.13
No. 100				0.97	1.14	2.11	1.02	1.41	2.43									
No. 200	0.5	1.0	1.5				0.55	1.17	1.72	0.52	0.61	1.13	0.60	0.64	1.24	0.59	0.76	1.35
AC	0.25	0.25	0.5	0.08	0.22	0.30	0.09	0.24	0.33	0.10	0.22	0.32	0.15	0.24	0.39	0.12	0.22	0.34

*No B-3 tested during 1967.

TABLE II

JOB MIX PRODUCTION AVERAGE AND VARIABILITY ANALYSIS
MIX TYPE B-3

·oject No.	Sample Size	¾" Sieve			No. 4 Sieve			No. 8 Sieve			No. 200 Sieve			Asphalt Content		
		JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total
43	64	0.47	2.27	3.74	1.26	o 3.49	o 4.75	-0.03	2.90	2.93	*o -1.08	0.86	o 1.94	-0.13	0.17	0.40
44	17	o 2.11	2.90	5.01	o 1.51	2.60	4.11	*o -2.86	2.13	o 4.99	0.43	0.23	0.66	0.19	0.22	0.41
46	16	-1.85	2.92	4.77	-1.34	o 3.02	4.36	o -2.77	2.49	o 5.26	*o 1.23	0.20	1.43	—	o 0.26	—
50	36	-1.05	3.05	4.10	0.18	2.36	2.54	-1.48	2.30	3.78	o -0.63	0.54	1.17	-0.16	0.19	0.35
53	18	-0.06	1.90	1.96	*o -4.01	2.07	o 6.08	-0.86	2.44	3.30	o 0.77	0.72	1.47	0.21	0.16	0.37
55	12	o -2.27	1.48	3.75	o -2.45	2.93	o 5.38	o -1.73	2.96	4.69	*o 0.62	0.18	0.80	0.09	o 0.29	0.38
56	4	o -4.05	2.90	o 6.95	o 1.85	2.24	4.09	1.07	1.46	2.53	-0.50	0.56	1.06	o 0.27	o 0.26	o 0.53
61	21	-0.25	2.27	2.52	o 2.05	o 3.22	o 5.27	1.03	o 3.23	4.26	-0.08	0.47	0.55	0.04	*o 0.33	0.37
62	108	0.83	3.43	4.26	*o -4.65	o 3.97	o 8.62	-0.85	2.86	3.71	-0.29	0.69	0.98	0.12	0.22	0.34
63	9	0.07	2.73	2.80	0.71	2.79	3.50	1.26	2.19	3.45	-0.48	0.82	1.30	0.18	0.18	0.36
64	20	0.61	1.68	2.29	*o -2.91	2.84	o 5.75	0.29	2.69	2.98	-0.32	0.72	1.04	-0.09	0.16	0.25
65	8	o -2.66	o 4.49	o 7.15	o -4.53	o 3.59	o 8.12	-0.74	2.42	3.16	0.12	0.60	0.72	0.09	0.17	0.26
66	8	o 2.53	2.45	4.98	-1.03	o 3.20	4.23	o -2.89	o 3.99	o 6.88	*o 1.46	0.26	o 1.72	0.21	0.23	0.44
67	35	-0.09	2.44	2.53	o -2.03	1.95	3.98	-0.32	2.10	2.42	0.13	o 1.06	1.19	0.05	0.18	0.23
68	21	0.89	2.25	3.14	*o -2.70	2.21	o 4.91	o 1.68	1.87	o 4.55	o -0.65	0.61	1.26	-0.02	0.17	0.19
69	37	1.68	2.26	3.94	-1.41	o 4.07	o 5.48	o 2.30	o 3.79	o 6.09	*o -0.89	o 1.09	o 1.98	-0.13	0.20	0.33
70	56	1.11	3.07	4.18	o -1.62	o 3.33	o 4.95	0.93	2.72	3.65	o -0.51	0.93	1.44	-0.07	*o 0.29	0.36
71	12	-0.74	3.04	3.78	o 2.26	o 3.99	o 6.25	-0.61	o 3.18	3.79	-0.30	o 1.13	1.43	-0.14	*o 0.77	o 0.91
90	18	o 3.31	o 4.00	o 7.31	o -2.36	o 3.71	o 6.07	0.05	o 3.39	3.44	0.03	0.94	0.97	0.12	*o 0.45	o 0.57
91	12	o -2.73	2.10	4.83	-1.36	2.59	3.95	0.00	2.51	2.51	*o 1.43	0.76	o 2.19	0.07	0.13	0.20
92	36	-1.08	1.63	2.71	0.52	1.60	2.12	1.21	1.04	1.25	0.15	0.40	0.55	0.06	0.13	0.19
93	20	-1.77	1.87	3.64	-0.65	2.91	3.56	1.42	1.95	3.37	o 0.81	0.70	o 1.51	-0.04	*o 0.32	0.36
94	8	-0.09	1.62	1.71	*o 3.86	1.91	o 5.77	o 1.65	1.58	3.23	o -0.88	0.46	1.34	0.01	0.18	0.19
95	8	o -3.30	*o 5.16	o 8.46	o -1.96	o 4.45	o 6.41	o 3.09	o 4.42	o 7.51	0.34	0.72	1.06	0.01	0.10	0.11
96	16	-0.59	2.20	2.79	0.23	1.54	1.77	o -1.95	2.13	4.08	-0.14	0.89	1.03	0.22	0.24	0.46
97	19	-0.07	*o 5.48	o 5.55	0.14	o 5.03	o 5.17	-1.21	o 4.09	o 5.30	o -0.68	0.49	1.17	-0.10	o 0.30	0.40
98	20	1.71	2.38	4.09	o -1.96	2.22	4.18	-0.46	1.73	2.19	0.47	0.37	0.84	-0.09	0.16	0.25
99	8	o -2.09	2.97	5.06	-0.76	2.76	3.52	0.05	1.56	1.61	-0.21	0.62	0.83	0.12	0.14	0.26
100	8	0.33	2.57	2.90	-0.22	1.84	2.06	o -2.89	1.68	o 4.57	o -0.61	0.35	0.96	-0.01	0.03	0.04
101	4	-1.67	1.28	2.95	o -2.45	o 3.63	o 6.08	0.35	0.77	1.12	0.02	0.30	0.32	0.05	0.06	0.11
102	4	-0.33	1.91	2.24	o 2.93	0.94	3.87	o 2.20	1.65	3.85	0.18	0.61	0.79	0.00	0.08	0.08
103	6	o 2.02	*o 5.30	o 7.32	1.27	o 4.13	o 5.40	-0.03	o 4.64	o 4.67	0.22	0.17	0.39	0.08	0.20	0.28
·erage		1.39	2.75	4.14	o 1.85	2.91	o 4.76	1.26	2.53	3.79	o 0.52	0.61	1.13	0.10	0.22	0.32
·lerance		2.00	3.50	5.50	1.50	3.00	4.50	1.50	3.00	4.50	0.50	1.00	1.50	0.25	0.25	0.50
·rcent Above Tolerance		31.2	15.6	18.7	56.2	43.8	53.1	34.3	25.0	31.2	43.7	9.4	15.6	3.2	28.1	9.4

Indicates value is statistically larger than specified values.

Indicates value is numerically larger than specified values.

TABLE III

JOB MIX PRODUCTION AVERAGE AND VARIABILITY ANALYSIS
MIX TYPE I-2

Project - M	Sample Size	3/8" Sieve			No. 4 Sieve			No. 8 Sieve			No. 50 Sieve			No. 200 Sieve			Asphalt Content		
		JM-$\bar{X}$	S	Total	JM-$\bar{X}$	S	Total	JM-$\bar{X}$	S	Total	JM-$\bar{X}$	S	Total	JM-$\bar{X}$	S	Total	JM-$\bar{X}$	S	Total
3	16										-0.73	0.92	1.65	-0.49	0.62	1.11	-0.08	0.14	0.22
5	5				-0.26	2.11	2.37				°-1.46	0.68	2.14	-0.44	0.40	0.88	°0.31	°0.35	°0.66
7	5				°-4.12	*°6.13	°10.25				°-3.28	*°4.63	°7.91	0.10	1.36	1.46	-0.01	0.25	0.26
8	14				-0.69	2.63	3.32				*°-2.25	1.43	°3.68	°-0.81	1.14	°1.95	-0.11	°0.27	0.38
14	14				-0.01	°3.82	3.83				0.18	0.88	1.06	-0.45	0.69	1.14	0.07	0.23	0.30
18	8				°-3.38	*°4.81	°8.19				-0.98	1.98	2.96	°-0.54	0.80	1.34	°-0.76	*°0.69	°1.45
19	12				-1.09	*°4.88	°5.97				-0.31	1.19	1.50	-0.19	0.58	0.77	0.17	°0.44	°0.61
24	16				0.37	2.58	2.95				°-1.51	1.44	2.95	*°-0.95	0.71	°1.66	0.04	0.22	0.26
25	8				-1.04	1.05	2.09				°-1.02	0.47	1.49	-0.14	0.31	0.45	0.00	0.21	0.21
26	11				-1.29	°3.91	°5.20				0.19	0.71	0.90	°-0.56	0.75	1.31	0.02	0.24	0.26
27	12	1.08	3.23	4.31	-0.79	2.54	3.33	-0.97	2.44	3.41	-0.74	1.32	2.06	*°-1.10	0.63	°1.73	0.19	0.20	0.39
28	9	-0.24	3.09	3.33	°-1.54	2.62	4.16	*°-5.16	2.46	°7.62	*°-3.22	°2.02	°5.24	°-1.02	1.26	°2.28	0.04	0.25	0.29
30	27	-0.97	2.37	3.34	-0.43	1.35	1.81	*°-2.84	1.25	4.09	-0.39	1.47	1.86	-0.19	0.92	1.11	-0.01	0.14	0.15
35	9				0.18	°3.65	°4.83				-0.70	0.67	1.37	0.28	0.37	0.65	-0.16	0.21	0.37
36	8				0.21	2.31	2.52				°1.47	1.12	2.59	°0.85	0.77	°1.62	0.08	°0.36	0.49
37	18				0.59	°3.17	3.76				0.83	1.23	2.06	0.31	1.00	1.31	*°0.63	0.07	°0.70
38	12				°-1.70	2.56	4.26				°-1.36	1.15	2.51	0.01	0.29	0.30	*°0.40	0.23	°0.63
39	11				-1.15	1.67	2.72				*°-1.77	0.82	2.59	0.15	0.60	0.75	0.18	*°0.60	°0.78
40	15				-0.46	2.44	2.90				-0.85	1.42	2.27	-0.06	0.75	0.81	0.23	0.15	0.38
43	8	°-2.53	°3.91	°6.44	°-2.22	*°4.90	°7.12	°1.52	*°4.72	°6.24	°-1.25	1.85	°3.10	°-0.54	0.99	°1.53	0.11	0.18	0.29
47	8				°-2.41	2.35	°4.76				°-1.70	1.19	2.89	*°-1.33	0.74	°2.07	°-0.35	0.25	°0.60
50	16				°-2.40	1.72	4.12	*°-2.88	1.44	4.32	-0.78	1.15	1.93	-0.29	0.56	0.87	-0.09	0.12	0.21
64	7	-1.24	°4.40	°5.64	°-2.23	1.85	4.05	-0.30	1.29	1.59	-0.23	0.96	1.19	-0.19	0.64	0.83	-0.07	0.20	0.27
68	7	-1.26	3.06	4.32	°-4.03	2.35	°6.38	°-2.06	°3.47	°5.53	-0.94	0.84	1.78	°-1.03	0.39	1.42	-0.04	0.21	0.25
69	8	°-5.92	°3.55	°9.47	-1.26	°3.21	4.47	-0.47	2.24	2.71	°-1.55	1.26	2.81	*°-1.48	0.63	°2.11	°-0.30	°0.26	°0.56
104	5	°2.86	1.75	4.61	°-2.66	1.76	4.42	°-3.40	1.67	5.07	-0.06	0.82	0.88	°-0.54	0.69	1.23	0.00	0.25	0.25
106	4	1.40	°4.21	°5.61	°-1.57	1.37	2.94	-0.95	0.79	1.74	0.50	0.78	1.28	°-0.60	0.36	0.96	0.11	0.20	0.31
107	4	0.70	3.39	4.09	°-2.25	°3.24	°5.49	-0.80	3.35	4.15	°-1.05	1.05	2.10	*°-1.30	0.29	°1.59	0.06	0.07	0.13
109	8				0.06	°4.19	4.25				°1.49	0.86	2.35	°0.77	1.02	1.39	-0.06	*°0.37	0.43
110	13				-0.38	1.57	1.95				0.53	0.68	1.21	*°0.93	0.33	1.26	-0.05	0.14	0.19
111	7				0.80	1.56	2.36				°-1.16	0.88	2.04	-0.43	0.87	1.30	-0.07	0.21	0.28
112	7				*°-3.31	1.01	4.32				-0.90	0.57	1.47	°0.91	0.58	1.49	0.06	0.05	0.11
113	4				0.70	1.62	2.32				°-2.32	0.75	°3.07	°0.70	0.58	1.28	0.21	0.02	0.23
114	4				-0.95	°3.75	°4.70				°-1.08	1.48	1.56	0.12	0.58	0.70	0.00	°0.36	0.36
115	4				°4.25	°3.29	°7.54				0.57	1.42	1.99	°-0.58	0.71	1.29	°-0.55	*°0.48	°1.03
116	7				0.67	2.59	3.26				-0.16	0.62	0.78	*°-1.33	0.32	°1.65	0.01	0.17	0.18
117	4				°2.27	1.12	3.39				0.45	0.75	1.20	°-0.52	0.46	0.98	0.13	*°0.47	°0.60
118	5				-1.36	0.56	1.92				-0.92	0.50	1.42	-0.46	0.18	0.64	0.00	0.10	0.10
119	5				°-2.58	°4.05	°6.63				°-1.36	1.67	°3.03	-0.16	1.16	1.32	0.22	0.15	0.37
120	8				-0.86	2.23	3.09				*°-1.80	0.60	2.40	-1.11	0.22	1.33	0.13	0.18	0.31
Average		1.82	3.30	5.12	1.50	2.68	4.18	1.94	2.20	4.14	1.10	1.15	2.25	°0.60	0.64	1.24	0.15	0.24	0.39
Tolerance		2.00	3.50	5.50	1.50	3.00	4.50	1.50	3.00	4.50	1.00	2.00	3.00	0.50	1.00	1.50	.25	.25	.50
Percent Above Tolerance		30.0	40.0	40.0	41.0	35.9	30.8	60.0	20.0	30.0	52.5	5.0	17.5	50.0	10.0	25.0	17.5	27.5	25.0

* Indicates value is statistically larger than specified values.

° Indicates value is numerically larger than specified values.

TABLE IV

JOB MIX PRODUCTION AVERAGE AND VARIABILITY ANALYSIS
MIX TYPE S-5

ct	Sample Size	¾" Sieve			No. 4 Sieve			No. 8 Sieve			No. 30 Sieve			No. 50 Sieve			No. 200 Sieve			Asphalt Content		
		JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total	JM-$\overline{X}$	S	Total
	4	-2.97 o	1.92	4.89	-3.20 o	2.41	5.61 o	-4.10 o	2.67	6.77 o	1.50	1.70	3.20	0.25	1.13	1.38	0.83 o	1.26 o	2.09 o	0.05	0.42 o	0.47
	3	-1.03	0.38	1.41	-0.40	1.32	1.72	-0.07	1.10	1.17	-1.37	0.31	1.68	0.60	0.26	0.86	-0.30	0.46	0.76	0.00	0.10	0.10
	4	-1.40	0.91	2.31	-0.57	2.79	3.36	-0.27	2.55	2.82	0.30	1.78	2.08	1.92 o	1.15	3.07 o	0.57 o	0.78	1.35	0.49 o	0.56 *o	1.05 o
	4	-1.67	0.33	2.00	-1.75 o	4.47 o	6.22 o	2.10 o	4.90 *o	7.00 o	0.50	2.41	2.91	-0.03	1.60	1.63	-0.65 o	0.91	1.56 o	-0.35 o	0.45 o	0.80 o
	10	-4.54 *o	1.00	5.54 o	0.02	1.48	1.50	-0.39	1.37	1.76	1.45	0.75	2.20	1.42 o	1.06	2.48	0.19	1.16 o	1.35	0.18	0.19	0.37
	5							-0.76	1.02	1.78	1.24	1.32	2.56				0.94 o	0.55	1.59 o	0.18	0.23	0.41
	4	-1.58	1.71	3.29	1.25	0.98	2.23	0.30	2.81	3.11	0.18	1.71	1.89	0.37	1.24	1.61	1.00 o	0.42	1.42	0.02	0.09	0.11
	3	-0.87	0.35	1.22	3.80 o	2.09	5.89 o	3.47 o	3.78 o	7.25 o	2.40 o	3.30 o	5.70 o	0.87	2.14 o	3.01 o	-0.37	0.95	1.32	0.00	0.45 o	0.45
	6	-1.05	1.14	2.19	2.25 o	1.54	3.79	2.40 o	1.12	3.52	3.00 *o	0.86	3.86	0.07	1.09	1.16	-1.27 o	0.46	1.73 o	-0.07	0.24	0.31
	13	-1.47	1.68	3.15	-0.74	3.70 o	4.44	-0.04	4.03 *o	4.07	2.85 o	2.92	5.77 o	-1.35 o	2.09 o	3.44 o	-0.57 o	1.08 o	1.65 o	-0.18	0.15	0.33
	8	0.12	1.00	1.12	0.94	2.88	3.82	1.18	1.51	2.69	-0.49	0.70	1.19	-0.10	0.78	0.88	0.45	0.63	1.08	0.01	0.22	0.23
	13	-4.43 *o	0.45	4.88	0.92	2.08	3.00	-0.01	1.87	1.88	-0.81	1.64	2.45	-1.59 o	0.92	2.51	0.57 o	0.65	1.22	-0.03	0.13	0.16
	15	-0.34	1.46	1.80	0.97	1.67	2.64	0.76	1.84	2.60	-0.83	1.14	1.97	-0.89	0.84	1.73	0.07	0.56	0.63	0.07	0.08	0.15
	24	-2.68 *o	0.90	3.58	-1.05	3.51 o	4.56 o	-1.69 o	3.76 *o	5.45 o	-2.06 o	2.09	4.15	-1.87 o	1.33	3.20 o	0.65 o	0.55	1.20	0.04	0.18	0.22
	17	0.64	1.20	1.84	-4.42 *o	4.55 *o	8.97 o	-3.29 o	4.36 *o	7.65 o	-0.88	2.05	2.93	0.44	1.47	1.91	0.99 o	0.61	1.60 o	-0.16	0.27 o	0.43
	8	-1.02	3.64 o	4.66	-2.66 o	1.51	4.17	2.49 o	1.71	4.20	2.79 *o	0.69	3.48	1.60 o	0.87	2.47	0.75 o	0.51	1.26	0.29 o	0.73 *o	1.02 o
	8							-3.06 o	3.05 o	6.11 o	-2.16 o	1.24	3.40				-0.16	0.27	0.43	0.10	0.28 o	0.38
	8	2.74 o	2.31	5.05	-2.36 o	2.18	4.54 o	-1.01	1.96	2.97	-0.10	2.10	2.20	-0.81	1.65	2.46	0.15	0.42	0.57	0.16	0.15	0.31
	4	2.10 o	0.62	2.72	1.98 o	1.89	3.87	-1.65 o	3.52 o	5.17 o	2.60 o	2.28	4.88 o	0.28	0.64	0.92	0.73 o	0.49	1.22	0.15	0.13	0.28
	11	-0.64	0.97	1.61	-2.91 o	2.10	5.01 o	-0.71	2.14	2.85	-0.12	1.01	1.13	-1.55 o	0.66	2.21	0.27	0.40	0.67	0.07	0.13	0.20
	13	-1.75	1.13	2.88	-1.02	1.90	2.92	0.02	1.32	1.34	-2.34 o	1.54	3.88	-1.54 o	1.07	2.61	-0.33	0.44	0.77	-0.10	0.12	0.22
	4	-0.90	1.17	2.07	5.20 *o	1.54	6.74 o	4.35 *o	1.14	5.49 o	0.82	1.51	2.33	-0.12	1.40	1.52	-0.77 o	1.54 o	2.31 o	0.34 o	—	—
	4	-1.78	3.05	4.83	0.30	3.53 o	3.83	0.82	3.15 o	3.97	0.48	2.14	2.62	0.37	1.73	2.10	0.55 o	0.95	1.50	-0.04	0.31 o	0.34
	24	-1.22	1.26	2.48	0.15	6.40 *o	6.55 o	0.70	5.59 o	6.29 o	0.45	3.44 o	3.89	-0.44	2.63 *o	3.07 o	-0.47	1.23 o	1.70 o	-0.01	0.29	0.30
	5	-1.12	0.71	1.83	4.46 o	2.83	7.29 o	-0.86	1.26	2.12	1.76 o	2.13	3.89	0.64	2.15 o	2.79	0.28	1.15 o	1.43	-0.08	0.22	0.30
	32	-2.32 o	1.15	3.47	-1.12	3.14 o	4.26	-1.41	2.73	4.14	-0.88	2.05	2.93	-0.03	1.47	1.50	-0.32	0.74	1.06	0.00	0.13	0.13
	6	-0.22	4.05 o	4.27	-4.03 o	7.78 *o	11.81 o	0.28	5.67 o	5.95 o	-0.63	5.43 *o	6.06 o	3.53 o	2.61 o	6.14 o	0.87 o	1.25 o	2.12 o	0.15	0.74 *o	0.89 o
	15	-3.25 *o	1.05	4.30	-0.66	2.84	3.50	0.36	3.28	3.64	-0.75	1.87	2.62	-0.50	1.03	1.53	0.46	0.59	1.05	-0.29	0.11	0.40
	6	-1.42	2.31	3.73	2.65 o	1.89	4.54	3.37 o	4.24 o	7.61 o	0.35	3.16 o	3.51	-1.87 o	2.04 o	3.91	-1.20 o	1.23 o	2.43 o	-0.81	0.34 o	0.52 o
	4	-1.00	0.72	1.72	-1.00	1.04	2.04	0.03	1.29	1.32	-1.93 o	1.33	3.26	0.53	0.67	1.20	0.95 o	0.13	1.08	-0.35 o	0.20	0.55 o
	5	0.20	0.62	0.82	1.16	3.12 o	4.28	0.18	3.79 o	3.97	-1.12	2.62	3.74	-0.34	1.47	1.81	0.90 o	0.35	1.25	-0.10	0.09	0.19
	4	1.52	0.68	2.20	2.68 o	2.58	5.26 o	-0.27	2.22	2.49	-3.18 o	1.22	4.40	-0.12	0.75	0.87	0.15	0.53	0.68	0.05	0.06	0.11
	5	-2.12 o	2.86	4.98	0.44	5.56 *o	6.00 o	-0.88	6.17 *o	7.05 o	-0.62	4.05 o	4.67 o	0.06	2.54 o	2.60	-0.64 o	1.35 o	1.99 o	-0.12	0.38 o	0.40
	7	-3.03 o	1.43	4.46	-0.67	4.20 o	4.87 o	-0.04	3.92 o	3.96	0.20	2.51	2.71	0.41	1.75	2.16	-0.16	0.96	1.12	-0.07	0.13	0.20
	4	-1.05	1.16	2.21	3.23 o	3.07 o	6.30 o	1.20	2.64	3.84	-0.42	0.89	1.31	-1.10 o	1.05	2.15	-0.50	0.73	1.23	-0.10	0.08	0.18
	4	-1.78	2.29	4.07	-2.10 o	2.41	4.51 o	-0.78	1.53	2.31	-1.60 o	0.27	1.87	-1.55 o	0.40	1.95	-0.35	0.88	1.23	-0.10	0.34 o	0.44
	5	-2.12 o	0.92	3.04	-4.80 o	4.82 *o	9.62 o	-0.56	2.54	3.10	3.14 *o	0.65	3.79	0.50	0.69	1.19	0.40	0.72	1.12	0.11	0.19	0.29
	14	-0.69	1.16	1.85	3.39 *o	1.96	5.35 o	1.86 o	1.44	3.30	-0.39	0.90	1.29	-0.16	1.11	1.27	-0.15	0.87	1.02	0.19	0.13	0.32
	6	-0.65	0.85	1.50	-4.23 *o	0.49	4.72 o	-3.27 o	2.50	5.77 o	-3.33 *o	1.06	4.39	-0.88	1.51	2.39	0.93 o	0.66	1.59 o	-0.23	0.31 o	0.54 o
	5							-2.04 o	2.60	4.64 o	-3.34 *o	0.90	4.24				0.82 o	0.72	1.54 o	0.16	0.11	0.27
	5							0.84	0.95	1.79	0.16	1.22	1.38				-0.42	0.55	0.97	0.14	0.13	0.27
	4							-1.90 o	3.94 o	5.84 o	-2.65 o	1.34	4.09				-0.80 o	0.96	1.76 o	0.06	0.14	0.20
	6							-1.18	2.20	3.38	-3.53 o	2.34	5.87 o				-1.38 o	0.89	2.27 o	0.01	0.10	0.11
	5							0.96	4.55 o	5.51 o	2.74 o	3.81 o	6.55 o				-1.00 o	1.01 o	2.01 o	0.03	0.31 o	0.34
	6							0.00	1.63	1.63	0.73	1.01	1.74				1.12 o	0.40	1.52 o	0.00	0.10	0.10
	6							1.08	2.98	4.06	-0.33	1.19	1.52				-0.53 o	1.43 o	1.96 o	0.00	0.30 o	0.30
	8							1.87 o	1.29	3.16	0.31	0.83	1.14				0.08	0.53	0.61	0.11	0.10	0.21
	4	-0.28	1.60	1.88	1.35	5.87 *o	7.22 o	-0.40	5.08 *o	5.48 o	-1.30	2.68	3.98	0.55	0.97	1.52	0.90 o	0.23	1.13	-0.15	0.21	0.36
	5							1.94 o	3.83 o	5.77 o	0.16	5.31 *o	5.47 o				0.18	0.88	1.06	-0.06	0.08	0.14
ge		1.57	1.37	2.94	2.02 o	2.90	4.92 o	1.29	2.79	4.08	1.37	1.87	3.24	0.82	1.31	2.13	0.59 o	0.76	1.35	0.12	0.22	0.34
ance		2.00	3.50	5.50	1.50	3.00	4.50	1.50	3.00	4.50	1.50	3.00	4.50	1.00	2.00	3.00	0.50	1.00	1.50	0.25	0.25	0.50
nt Above erance		28.9	5.3	2.6	50.0	36.8	52.6	36.2	40.4	38.3	38.3	14.9	17.0	31.6	18.4	15.8	55.1	23.4	36.7	12.8	34.0	14.8

icates value is statistically larger than specified values.

icates value is numerically larger than specified values.

Job Mix Formula vs. Production Average

From Table II, it appears that the No. 4 and No. 200 sieves do not consistently hit close to the job mix. This is evident from the magnitude of the grand averages at the bottom of each table. The same can be said for the data in Table III for the I-2 mixes, which appear to have problems on the No. 50 sieve. The S-5 mixes in Table IV also have problems with the No. 4 and No. 200 sieves, as well as spotty problems on all sieves and the asphalt content.

This problem is actually more academic than practical from a specification standpoint because the specification per se does not control this difference. If the production average differs appreciably from the job mix formula the difference will be discovered because the average of four samples will be out of the prescribed tolerance. However, it is enlightening from a technological viewpoint to determine how close a contractor can operate to the value that he states in the job mix formula. And, by and large, he can do fairly well.

Variability of Lot Means vs. Statistical Limits

As was stated previously, the variability of the lot means is made up of the ability to "hit" the job mix (discussed above) and the product variability. Although there are some values for the 1970 production that are larger than those used to establish the overall tolerance, namely the No. 4 sieve and asphalt content, they approach the estimated values very closely.

It is apparent from the grand averages that the No. 4 sieve consistently has more total variability than the statistical limits allow; hence the tolerances are somewhat too restrictive for this particular sieve. It is obvious from the percent above the tolerance that there is a great deal of inconsistency from sieve to sieve. As an example of this, for the S-5 projects in Table IV, only 2.6% of the mixes are above the 5.50 tolerance on the $\frac{3}{8}$" sieve, whereas 52.6% are above the No. 4 sieve tolerance of 4.50.

Total Standard Deviation vs. Total Standard Deviation Limits

When the tolerances for standard deviation were initially established, they were purposefully made much wider than the existing data indicated was necessary. There were two basic reasons for this. First, the tolerance was applied to the total tonnage and in case a plant was out on more than one screen, the prescribed adjustment could be expensive. Second, it was the first time a standard deviation tolerance had been tried.

Therefore it is not surprising to find almost no cases where the standard deviation exceeded that allowed in the specification. It appears that the limits on which the adjustment system is based for standard deviation are so large in comparison to the variability of the product as to be almost useless for product control.

Other Analyses

Range vs. Standard Deviation for Variability Control

It is generally accepted that some form of variability control is necessary in any well designed end result specification. The standard deviation as determined at the end of the project was thought to be the best form when the present specification was developed. A possible improvement to the present procedure is to use the range on each lot as an estimate of the standard deviation because of the simplicity of this determination and because it is the commonly accepted method of determining variability in production processes.

In this analysis, the first question that had to be answered was how well the range predicted the standard deviation. The applicable statistical formula for predicting the standard deviation (S) from the range (R) for sample groups of 4 is

$$S_r = R \times 0.5$$

where S_r = the standard deviation estimated from the range.

Tables V, VI, and VII show the calculated standard deviations, the standard deviations estimated from the average range, and the F ratio obtained by dividing the squared value of the largest standard deviation by the squared value of the smallest standard deviation (F). These F values were checked for significance at a 95% confidence level. A significant difference existed only 8 times out of a possible 160, or in 5% of the cases. The I-2 had no significant difference in 181 comparisons, and the S-5 only two out of 296, or 0.7% of the cases. It is interesting to note that in each case where there was a significant difference, the range underpredicted the standard deviation. The great occurrence of no significant differences is certainly evidence that the range method can accurately and consistently predict the standard deviation, and that there is no statistical reason for not using the range method as a variability control.

TABLE V

RANGE VS. STANDARD DEVIATION
MIX TYPE B-3

Project	No. of Lots	¾" Sieve			No. 4 Sieve			No. 8 Sieve			No. 200 Sieve			Asphalt Content		
		S	S_r	F	S	S_r	F	S	S_r	F	S	S_r	F	S	S_r	F
43	16	2.27	2.08	1.20	3.49	3.60	1.07	2.90	3.14	1.17	0.86	0.60	2.09*	0.17	0.17	1.06
44	4	2.79	2.75	1.03	2.66	2.91	1.20	2.17	2.26	1.08	0.24	0.26	1.22	0.23	0.21	1.16
46	4	2.92	2.98	1.04	3.02	2.72	1.23	2.49	2.50	1.01	0.20	0.21	1.18	0.26	0.30	1.31
50	9	3.05	2.70	1.27	2.36	1.59	2.20*	2.30	1.60	2.08*	0.54	0.45	1.47	0.19	0.18	1.02
53	4	1.98	1.98	1.00	2.17	2.32	1.15	2.49	2.43	1.04	0.66	0.62	1.11	0.16	0.16	1.00
55	3	1.48	1.70	1.33	2.93	2.83	1.07	2.96	2.83	1.09	0.18	0.18	1.04	0.29	0.31	1.18
56	1	2.90	2.70	1.15	2.24	2.30	1.06	1.46	1.60	1.21	0.56	0.65	1.35	0.26	0.30	1.30
61	5	2.30	2.69	1.37	3.28	4.06	1.53	3.10	3.17	1.04	0.48	0.58	1.46	0.33	0.35	1.10
62	27	3.43	2.80	1.50*	3.97	3.13	1.60*	2.86	2.50	1.30	0.69	0.58	1.39	0.22	0.18	1.58*
63	2	2.87	3.28	1.30	2.84	3.32	1.37	2.32	2.05	1.28	0.86	1.07	1.58	0.17	0.13	1.56
64	5	1.68	1.81	1.16	2.84	2.50	1.29	2.69	2.51	1.15	0.72	0.82	1.28	0.16	0.13	1.59
65	2	4.49	3.38	1.77	3.59	2.25	2.54	2.42	2.35	1.06	0.60	0.62	1.09	0.17	0.15	1.23
66	2	2.45	2.48	1.02	3.20	3.58	1.25	3.99	4.30	1.16	0.26	0.22	1.35	0.23	0.26	1.24
67	8	2.44	2.52	1.06	1.85	2.00	1.17	2.09	1.94	1.16	1.11	0.69	2.59	0.18	0.18	1.04
68	5	2.23	1.43	2.43*	2.16	2.24	1.08	1.82	1.50	1.47	0.62	0.76	1.48	0.16	0.16	1.00
69	9	2.28	2.21	1.06	4.12	3.30	1.55	3.84	3.04	1.59	1.11	0.80	1.90*	0.21	0.18	1.41
70	14	3.07	3.28	1.14	3.33	3.74	1.27	2.72	2.79	1.05	0.93	0.82	1.30	0.29	0.31	1.18
71	3	3.04	3.35	1.21	3.99	4.11	1.07	3.18	3.61	1.29	1.13	1.11	1.02	0.77	0.89	1.34
90	4	4.23	3.22	1.72	3.39	3.40	1.00	3.37	3.62	1.16	0.98	0.64	2.34	0.44	0.52	1.36
91	3	2.10	1.71	1.49	2.59	2.38	1.18	2.51	2.50	1.01	0.76	0.68	1.22	0.13	0.21	1.49
92	9	1.63	1.33	1.50	1.60	1.51	1.12	1.04	0.95	1.19	0.40	0.33	1.46	0.13	0.10	1.78*
93	5	1.87	2.04	1.19	2.91	2.68	1.18	1.95	1.86	1.10	0.70	0.73	1.08	0.32	0.24	1.69
94	2	1.62	1.82	1.26	1.91	1.78	1.16	1.58	1.55	1.03	0.46	0.52	1.31	0.18	0.13	1.85
95	2	5.16	6.12	1.41	4.45	4.35	1.05	4.42	5.48	1.53	0.72	0.52	1.90	0.10	0.10	1.02
96	4	2.20	1.94	1.29	1.54	1.51	1.04	2.13	1.42	2.23	0.89	0.75	1.40	0.24	0.20	1.40
97	4	5.88	5.25	1.26	4.81	2.82	2.89*	3.54	2.30	2.37	0.53	0.42	1.54	0.30	0.28	1.17
98	5	2.38	2.60	1.20	2.22	1.66	1.79	1.73	1.46	1.41	0.37	0.42	1.30	0.16	0.16	1.14
99	2	2.97	3.25	1.20	2.76	2.95	1.14	1.56	1.72	1.23	0.62	0.65	1.11	0.14	0.15	1.12
100	2	2.57	2.12	1.46	1.84	1.41	1.66	1.68	1.65	1.04	0.35	0.38	1.12	0.03	0.02	1.29
101	1	1.28	1.40	1.20	3.63	4.15	1.31	0.77	0.80	1.07	0.30	0.35	1.37	0.06	0.05	1.33
102	1	1.91	2.30	1.44	0.94	0.95	1.02	1.65	1.75	1.12	0.61	0.70	1.33	0.08	0.10	1.50
103	1	5.46	6.10	1.25	5.12	5.35	1.09	4.95	5.25	1.13	0.18	0.20	1.20	0.26	0.30	1.30
Average		2.78	2.73		2.93	2.79		2.52	2.45		0.61	0.57		0.22	0.22	

* Significant at 95% confidence level.

RANGE VS. STANDARD DEVIATION
MIX TYPE I-2

Project	No. of Lots	$\frac{3}{8}$" Sieve S	$\frac{3}{8}$" Sieve S_r	$\frac{3}{8}$" Sieve F	No. 4 Sieve S	No. 4 Sieve S_r	No. 4 Sieve F	No. 8 Sieve S	No. 8 Sieve S_r	No. 8 Sieve F	No. 50 Sieve S	No. 50 Sieve S_r	No. 50 Sieve F	No. 200 Sieve S	No. 200 Sieve S_r	No. 200 Sieve F	Asphalt Content S	Asphalt Content S_r	Asphalt Content F
3	4										0.92	0.86	1.14	0.62	0.68	1.18	0.14	0.14	1.09
5	1				2.27	2.65	1.37				0.75	0.80	1.14	0.45	0.50	1.21	0.38	0.42	1.28
7	1				6.67	7.25	1.18				5.25	5.15	1.04	1.43	1.60	1.26	0.25	0.30	1.40
8	3				2.76	1.96	1.97				1.46	1.10	1.77	1.11	1.04	1.16	0.27	0.20	1.88
14	3				4.14	3.75	1.22				0.94	1.00	1.13	0.74	0.85	1.32	0.22	0.19	1.37
18	2				4.81	5.75	1.43				1.98	2.05	1.07	0.80	0.90	1.25	0.69	0.81	1.42
19	3				4.88	5.50	1.27				1.19	1.36	1.31	0.58	0.65	1.29	0.44	0.37	1.45
24	4				2.58	2.80	1.18				1.44	1.66	1.34	0.71	0.75	1.10	0.22	0.16	1.73
25	2				1.05	0.80	1.73				0.47	0.50	1.16	0.31	0.32	1.09	0.21	0.21	1.07
26	2				4.26	4.50	1.12				0.82	0.92	1.26	0.88	1.05	1.44	0.17	0.20	1.24
27	3	3.23	3.40	1.11	2.54	2.61	1.06	2.44	2.66	1.20	1.32	1.35	1.04	0.63	0.65	1.07	0.20	0.21	1.17
28	2	3.11	2.52	1.52	2.56	2.65	1.07	2.59	3.28	1.59	2.11	2.68	1.61	1.27	1.60	1.59	0.27	0.26	1.06
30	6	2.21	2.52	1.30	1.42	1.50	1.12	1.28	1.28	1.00	1.37	1.20	1.30	0.96	0.82	1.34	0.14	0.14	1.09
35	2				3.88	4.00	1.06				0.52	0.58	1.21	0.36	0.40	1.22	0.20	0.20	1.03
36	2				2.31	2.70	1.36				1.12	1.02	1.19	0.77	0.45	2.92	0.36	0.42	1.41
37	4				2.81	2.82	1.01				1.30	1.52	1.37	0.96	1.11	1.34	0.07	0.08	1.13
38	3				2.56	2.60	1.03				1.15	1.06	1.17	0.29	0.20	2.07	0.23	0.21	1.25
39	2				1.76	1.28	1.90				0.66	0.55	1.43	0.20	0.20	1.02	0.71	0.50	2.00
40	3				1.84	1.58	1.35				1.40	1.33	1.10	0.70	0.75	1.16	0.15	0.12	1.66
43	2	3.91	4.55	1.35	4.90	5.98	1.49	4.72	5.28	1.25	1.85	1.55	1.42	0.99	0.75	1.74	0.18	0.20	1.16
47	2				2.35	2.32	1.02				1.19	0.62	3.61	0.74	0.40	3.42	0.25	0.18	1.72
50	4	1.52	1.37	1.22	1.72	1.58	1.20	1.44	1.44	1.01	1.15	1.00	1.32	0.56	0.51	1.18	0.12	0.08	2.32
64	1	4.16	5.00	1.44	2.26	2.65	1.37	1.48	1.75	1.39	1.16	1.15	1.02	0.86	1.00	1.36	0.28	0.31	1.27
68	1	2.96	3.60	1.48	2.71	3.10	1.31	4.45	5.05	1.29	0.92	1.10	1.43	0.40	0.45	1.24	0.14	0.16	1.46
69	2	3.55	4.10	1.34	3.21	2.80	1.31	2.24	2.32	1.08	1.26	1.02	1.51	0.63	0.70	1.25	0.26	0.26	1.04
104	1	1.54	1.70	1.23	1.41	1.60	1.28	1.87	2.05	1.20	0.90	1.00	1.23	0.74	0.75	1.02	0.29	0.27	1.13
106	1	4.21	5.10	1.47	1.37	1.50	1.20	0.79	0.90	1.29	0.78	0.85	1.19	0.36	0.35	1.03	0.20	0.23	1.39
107	1	3.39	3.85	1.29	3.24	3.80	1.37	3.35	3.25	1.06	1.05	1.25	1.42	0.29	0.30	1.04	0.07	0.08	1.38
109	2				4.19	3.00	1.95				0.86	1.00	1.34	1.02	0.95	1.15	0.37	0.32	1.32
110	3				1.61	1.56	1.06				0.69	0.76	1.23	0.35	0.36	1.11	0.09	0.09	1.07
111	1				0.81	0.90	1.25				0.67	0.70	1.10	0.35	0.35	1.01	0.05	0.05	1.00
112	1				1.09	1.30	1.42				0.26	0.30	1.29	0.24	0.25	1.10	0.06	0.05	1.33
113	1				1.62	1.40	1.33				0.75	0.80	1.12	0.58	0.55	1.12	0.02	0.02	1.20
114	1				3.75	3.80	1.03				1.48	1.80	1.48	0.58	0.70	1.46	0.36	0.40	1.26
115	1				3.29	3.90	1.40				1.42	1.60	1.26	0.71	0.75	1.12	0.48	0.50	1.09
116	1				2.34	2.60	1.23				0.49	0.45	1.20	0.17	0;20	1.37	0.24	0.25	1.07
117	1				1.12	1.35	1.46				0.75	0.80	1.14	0.46	0.50	1.20	0.47	0.50	1.16
118	1				0.64	0.75	1.37				0.22	0.25	1.27	0.14	0.15	1.12	0.10	0.10	1.09
119	1				3.33	3.90	1.37				1.34	1.55	1.33	0.74	0.85	1.33	0.17	0.18	1.06
120	2				2.23	2.30	1.07				0.60	0.50	1.44	0.22	0.27	1.61	0.18	0.15	1.46
Average		3.07	3.43		2.67	2.79		2.42	2.66		1.15	1.17		0.62	0.64		0.24	0.24	

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TABLE VII

RANGE VS. STANDARD DEVIATION

MIX TYPE S-5

Project	No. Lots	3/8" Sieve S	3/8" Sieve S_r	3/8" Sieve F	No. 4 Sieve S	No. 4 Sieve S_r	No. 4 Sieve F	No. 8 Sieve S	No. 8 Sieve S_r	No. 8 Sieve F	No. 30 Sieve S	No. 30 Sieve S_r	No. 30 Sieve F	No. 50 Sieve S	No. 50 Sieve S_r	No. 50 Sieve F	No. 200 Sieve S	No. 200 Sieve S_r	No. 200 Sieve F	Asphalt Content S	Asphalt Content S_r	Asphalt Content F
1	1	1.92	1.90	1.40	2.41	2.90	1.44	2.67	2.25	1.06	1.70	1.85	1.19	1.13	1.20	1.12	1.26	1.50	1.42	0.42	0.50	1.42
6	1	0.91	1.00	1.20	2.79	2.80	1.00	2.55	2.70	1.12	1.78	2.10	1.40	1.15	1.25	1.18	0.78	0.90	1.34	0.56	0.62	1.20
8	1	0.33	0.35	1.12	4.47	5.00	1.25	4.90	5.25	1.15	2.41	2.90	1.44	1.60	1.95	1.48	0.91	1.05	1.33	0.45	0.50	1.26
10	2	1.00	0.95	1.11	1.51	1.60	1.12	1.45	1.10	1.75	0.76	0.83	1.17	1.20	1.13	1.13	1.31	1.20	1.19	0.20	0.23	1.41
11	1	—	None	—	—	None	—	1.14	1.25	1.21	1.47	1.70	1.34	—	None	—	0.17	0.20	1.37	0.24	0.29	1.49
12	1	1.71	1.85	1.17	0.98	1.20	1.48	2.81	3.20	1.30	1.71	2.00	1.37	1.24	1.35	1.18	0.42	0.45	1.13	0.09	0.10	1.23
15	1	1.16	1.30	1.25	1.87	1.95	1.09	1.03	1.10	1.14	1.09	1.15	1.11	1.39	1.60	1.33	0.59	0.65	1.21	0.14	0.15	1.12
16	3	1.73	1.30	1.77	3.85	3.47	1.23	4.21	3.80	1.23	3.04	2.82	1.16	2.18	2.20	1.02	1.10	1.15	1.10	0.16	0.19	1.39
21	2	1.00	1.18	1.37	2.88	2.45	1.38	1.51	1.53	1.02	0.70	0.75	1.16	0.78	0.95	1.47	0.63	0.73	1.32	0.22	0.26	1.35
29	3	0.45	0.49	1.14	2.17	2.49	1.31	1.84	1.75	1.11	1.71	1.24	1.91	0.90	0.77	1.39	0.67	0.65	1.05	0.13	0.10	1.70
31	3	1.47	1.64	1.23	1.81	1.94	1.14	2.01	1.50	1.79	0.78	0.87	1.22	0.59	0.74	1.54	0.63	0.62	1.03	0.07	0.08	1.30
32	6	0.90	0.95	1.10	3.51	3.50	1.01	3.76	3.83	1.03	2.09	2.18	1.08	1.33	1.16	1.32	0.55	0.50	1.23	0.18	0.11	2.77*
34	4	1.24	1.10	1.27	4.65	5.06	1.19	4.49	4.65	1.07	2.07	2.25	1.18	1.51	1.65	1.20	0.61	0.68	1.21	0.27	0.28	1.03
41	2	3.64	2.58	2.00	1.51	1.28	1.40	1.71	1.45	1.39	0.69	0.85	1.52	0.87	0.73	1.42	0.51	0.60	1.37	0.73	0.55	1.79
42	2	—	None	—	—	None	—	3.05	3.85	1.59	1.24	1.43	1.33	—	None	—	0.27	0.33	1.43	0.28	0.24	1.36
44	2	2.31	2.03	1.19	2.18	2.53	1.35	1.96	1.95	1.01	2.10	2.20	1.10	1.65	1.50	1.21	0.42	0.45	1.13	0.15	0.19	1.51
50	1	0.62	0.65	1.11	1.89	2.05	1.18	3.52	4.15	1.39	2.28	2.75	1.45	0.64	0.65	1.03	0.49	0.45	1.20	0.13	0.15	1.35
51	2	0.77	0.83	1.14	2.41	2.10	1.32	2.45	2.35	1.09	1.16	1.23	1.12	0.73	0.78	1.13	0.39	0.48	1.45	0.14	0.13	1.25
53	3	1.16	1.17	1.01	1.90	2.40	1.59	1.22	1.00	1.48	1.60	1.00	2.55	1.11	0.62	2.78	0.48	0.50	1.18	0.12	0.11	1.18
63	1	1.17	1.35	1.32	1.54	1.85	1.45	1.14	1.25	1.21	1.51	1.65	1.19	1.40	1.65	1.39	1.54	1.70	1.22	0	0	0
64	1	3.05	3.60	1.39	2.26	2.65	1.37	1.48	1.75	1.39	—	None	—	1.16	1.15	1.02	0.86	1.00	1.36	0.28	0.32	1.27
65	6	1.26	1.34	1.13	6.40	5.25	1.49	5.59	4.55	1.51	3.44	2.67	1.66	2.63	2.22	1.40	1.23	1.14	1.18	0.29	0.29	1.02
66	1	0.78	0.85	1.19	2.78	2.90	1.09	0.93	0.95	1.05	1.38	1.45	1.11	0.81	0.90	1.25	0.38	0.45	1.42	0.26	0.30	1.35
67	8	1.15	1.10	1.10	3.14	2.72	1.29	2.73	2.52	1.18	2.05	1.78	1.33	1.47	1.30	1.28	0.74	0.75	1.02	0.13	0.13	1.02
68	1	1.85	2.20	1.41	3.13	3.50	1.25	0.70	0.80	1.32	2.82	3.05	1.17	2.54	2.80	1.22	1.52	1.70	1.24	0.05	0.05	1.00
69	3	1.01	0.89	1.30	3.09	2.50	1.53	3.35	2.65	1.60	1.88	1.22	2.38	1.01	0.59	2.98*	0.64	0.62	1.08	0.11	0.12	1.18
70	1	2.94	2.90	1.03	1.96	2.35	1.44	5.37	5.90	1.21	3.90	4.70	1.45	2.61	2.85	1.19	1.58	1.85	1.37	0.25	0.22	1.08
72	1	0.72	0.85	1.41	1.04	1.25	1.46	1.29	1.55	1.43	1.33	1.50	1.27	0.67	0.80	1.45	0.13	0.15	1.35	0.20	0.24	1.45
73	1	0.64	0.75	1.35	3.27	3.60	1.21	4.06	4.85	1.15	2.26	2.45	1.17	1.33	1.40	1.11	0.25	0.25	1.00	0.10	0.11	1.11
74	1	0.68	0.80	1.38	2.58	3.00	1.35	2.22	2.80	1.07	1.22	1.25	1.05	0.75	0.90	1.44	0.53	0.50	1.11	0.06	0.05	1.33
75	1	3.28	4.00	1.49	6.39	7.60	1.42	7.11	7.85	1.22	4.66	5.30	1.29	2.93	3.40	1.34	1.52	1.70	1.24	0.43	0.46	1.15
76	1	0.41	0.40	1.06	3.96	3.85	1.06	2.90	3.50	1.46	1.52	1.65	1.18	1.17	1.30	1.23	1.14	1.40	1.50	0.17	0.20	1.33
77	1	1.16	1.35	1.35	3.07	3.40	1.23	2.64	2.80	1.13	0.89	1.00	1.27	1.05	1.20	1.30	0.73	0.80	1.19	0.08	0.10	1.50
78	1	2.29	2.60	1.29	2.41	2.75	1.30	1.53	1.40	1.20	0.27	0.30	1.23	0.40	0.45	1.24	0.88	0.85	1.07	0.34	0.40	1.34
79	1	1.05	1.05	1.00	5.41	6.60	1.49	2.89	3.40	1.38	0.73	0.80	1.21	0.79	0.85	1.15	0.77	0.85	1.21	0.21	0.25	1.46
80	3	1.24	1.49	1.43	2.13	2.19	1.05	1.56	1.37	1.31	0.96	0.97	1.02	1.20	1.30	1.17	0.94	1.07	1.29	0.14	0.17	1.41
81	1	1.09	1.20	1.22	0.34	0.40	1.38	3.17	3.80	1.43	1.19	1.45	1.49	1.89	2.15	1.29	0.79	0.90	1.30	0.40	0.41	1.06
82	1	—	None	—	—	None	—	2.89	3.35	1.34	0.97	1.10	1.27	—	None	—	0.82	0.90	1.20	0.13	0.15	1.35
83	1	—	None	—	—	None	—	1.05	1.20	1.30	1.05	1.25	1.42	—	None	—	0.63	0.70	1.22	0.10	0.13	1.47
84	1	—	None	—	—	None	—	3.94	4.75	1.45	1.34	1.60	1.42	—	None	—	0.96	1.10	1.32	0.14	0.16	1.23
85	1	—	None	—	—	None	—	2.53	2.80	1.22	2.40	2.40	1.00	—	None	—	0.87	0.95	1.20	0.11	0.14	1.45
86	1	—	None	—	—	None	—	4.35	4.90	1.27	3.97	4.30	1.17	—	None	—	1.01	1.20	1.42	0.33	0.35	1.14
87	1	—	None	—	—	None	—	1.82	1.85	1.03	0.72	0.85	1.41	—	None	—	0.48	0.55	1.32	0.13	0.15	1.35
88	1	—	None	—	—	None	—	3.72	4.40	1.40	1.41	1.60	1.29	—	None	—	0.90	1.05	1.37	0.31	0.34	1.19
89	2	—	None	—	—	None	—	1.65	1.85	1.26	1.07	1.25	1.36	—	None	—	0.71	0.85	1.42	0.06	0.07	1.46
121	1	1.60	1.80	1.26	5.87	6.15	1.10	5.08	5.45	1.15	2.68	2.75	1.06	0.97	1.05	1.16	0.23	0.20	1.33	0.21	0.24	1.28
123	1	—	None	—	—	None	—	4.40	4.95	1.27	6.11	6.50	1.13	—	None	—	0.99	1.15	1.36	0.08	0.09	1.14
Average		1.38	1.44		2.88	3.03		2.77	2.93		1.83	1.93		1.30	1.35		0.76	0.84		0.21	0.23	

Standard Deviation vs. Length of Operation

It has been thought that the longer a plant operated the more consistent the product would become. It has also been thought that during the first day or two the operation was extremely susceptible to variability. In order to verify or refute these contentions an analysis was made of accumulated standard deviations plotted against the numbers of lots tested for projects with three or more lots. This analysis resulted in graphs for each project and each mix as typified in Figure 2. The graphs were examined and the variability of each sieve was judged to be stable (S), increasing (I) or decreasing (D). The results are tabulated in Tables VIII, IX, and X for the 2nd lot to the end of the project and the trends from the 1st to the 2nd lot. The totals are summarized at the bottom of each table.

The first observations are that about 50% of the project variabilities tend to remain stable, and slightly more increase than decrease. It also appears that the variabilities of the #200 sieve and the asphalt content tend to remain more stable than do those for the other sieves. These observations tend to refute the contention that the variability decreases over time of operation. Also, between the first and second lots, particularly for B-3 mixes, the variability increases more often than it does for the entire project. For instance, on the B-3 there were 35 occasions of increased variabilities on the entire project, but 48 increases between the first and second lots. It appears that, by and large, inclusion of the first lot in the calculation of variability does not provide an over prediction of standard deviation, but may actually tend to reduce it.

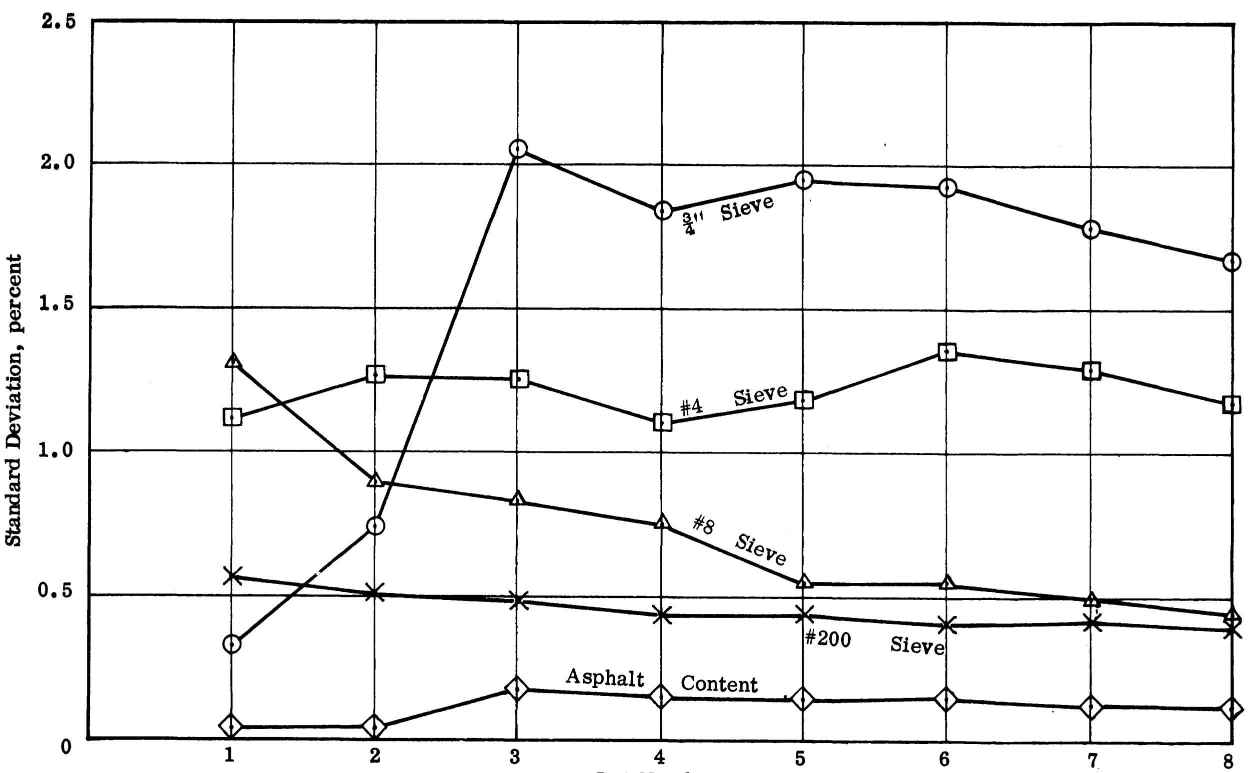

Figure 2. Typical association between variability and time.

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TABLE VIII

VARIABILITY VS. TIME
MIX TYPE B-3

Project	No. Lots	3/4" Sieve		# 4 Sieve		# 8 Sieve		# 200 Sieve		Asphalt Content		Total	
		2nd - End	1st -2nd	2nd -End	1st - 2nd	2nd - End	1st - 2nd	2nd - End	1st - 2nd	2nd - End	1st - 2nd	2nd -End	1st=2nd
43	16	D	D	I	D	I	D	S	I	S	I		
44	4	D	S	D	S	D	I	S	I	S	I		
46	4	S	I	I	D	I	D	S	D	S	S		
50	8	I	I	D	I	D	I	I	I	S	D		
53	4	D	D	S	S	I	S	S	I	S	D		
55	3	I	I	I	I	I	I	S	S	S	I		
61	5	S	I	I	S	I	D	S	D	S	S		
62	16	S	I	D	S	D	D	S	D	S	I		
64	5	S	D	I	I	I	I	S	S	S	S		
67	6	D	I	S	D	S	D	I	S	I	S		
68	5	I	S	I	S	I	S	S	S	S	S		
69	8	I	I	D	I	S	I	I	I	S	I		
70	14	I	I	I	I	I	D	I	D	S	I		
71	3	S	I	S	I	S	I	S	I	S	D		
90	4	I	I	S	I	S	I	S	D	S	I		
91	3	D	D	D	I	D	D	I	S	S	S		
92	8	I	I	S	I	D	D	S	S	I	S		
93	5	D	D	D	D	S	D	S	D	S	D		
96	4	S	I	I	S	I	I	S	D	I	S		
97	4	S	S	I	I	S	I	S	I	I	I		
98	5	D	D	I	I	S	I	S	S	S	S		
Totals:	Increase	7	12	10	11	9	10	5	7	4	8	35	48
	Stable	7	3	5	6	7	2	16	7	17	9	52	29
	Decrease	7	6	6	4	5	9	0	7	0	4	18	30

TABLE IX

VARIABILITY VS. TIME
Mix Type I-2

Project	No. Lots	3/8" Sieve		# 4 Sieve		# 30 Sieve		# 50 Sieve		# 200		A. C.		Total	
		2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd
03	4	-	-	-	-	-	-	D	S	D	S	S	S		
08	3	-	-	-	-	-	-	I	D	I	D	S	S		
14	3	-	-	-	-	-	-	S	D	I	D	S	S		
16	3	I	I	S	D	D	D	D	D	S	I	S	S		
19	3	-	-	I	I	-	-	S	I	S	I	S	S		
24	4	-	-	D	I	-	-	S	I	I	D	S	S		
27	3	D	I	D	D	D	D	D	I	S	I	S	S		
30	6	D	I	D	I	D	D	I	S	I	D	S	D		
37	4	-	-	I	I	-	-	S	S	S	S	S	S		
38	3	-	-	D	D	-	-	S	S	S	S	I	S		
40	3	-	-	S	S	-	-	D	I	D	D	S	S		
50	4	I	I	I	D	S	I	I	S	S	S	S	S		
110	3	-	-	S	D	-	-	D	D	S	I	S	S		
Total	Increase	2	4	3	4	0	1	3	4	4	4	1	0	13	17
	Stable	0	0	3	1	1	0	5	5	7	4	12	12	28	22
	Decrease	2	0	4	5	3	3	5	4	2	5	0	1	16	18

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TABLE X

VARIABILITY VS. TIME
MIX TYPE S-5

Project	No. Lots	3/8 "		# 4		#8		# 30		# 50		# 300		A. C.		Total	
		2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd	2nd-End	1st-2nd
29	3	S	S	D	S	S	S	I	I	I	I	S	D	S	S		
31	3	D	D	S	I	I	I	S	S	S	S	S	D	S	S		
32	6	D	I	D	D	D	D	D	D	D	D	S	S	S	S		
34	4	S	I	S	D	S	D	S	D	D	D	S	D	S	S		
53	3	S	D	S	D	I	D	I	I	I	I	S	S	I	S		
65	6	I	S	D	D	D	D	D	D	D	D	D	D	I	S		
67	8	I	I	I	D	I	I	I	D	S	D	S	D	S	S		
69	3	I	I	I	I	I	I	I	I	I	I	I	S	S	D		
80	3	S	I	S	I	S	I	S	I	D	I	S	I	S	S		
Totals																	
Increase		3	5	2	3	4	4	4	4	3	4	1	1	2	0	19	21
Stable		4	2	4	1	3	1	3	1	2	1	7	3	7	8	30	17
Decrease		2	2	3	5	2	4	2	4	4	4	1	5	0	1	14	25

Standard Deviation of Batch Plants vs. Continuous Plants

Of the 108 different projects, only 8 used mixes from continuous plants. This number does not allow a very sophisticated analysis to be made, because of the overwhelming number of batch plants compared to continuous plants. Of the 8 mixes, one was a B-3, three were S-5, and four were I-2 mixes.

A comparison of the average production of each continuous plant with the overall average production of each mix type indicates that generally the total values, as listed in Tables II, III, and IV, are greater for the continuous plants than for all plants. There was one continuous plant that produced a mix with a lower total value than the overall average. The most noticeable evidence of lack of consistency in the continuous plants is the average total value for asphalt content, which was 0.50% as opposed to 0.35% for all plants.

Variability Between Truck Quadrants Within A Project

In the initial study, made in 1967, it was found that several plants produced a total mix within specified tolerances but had substantial variations within a truck. This was attributed to incomplete mixing, probably because of problems within the pug mill. Since the data were available it seemed reasonable to check quadrants for significant differences. Only projects containing 2 or more lots were analyzed and every possible combination between quadrant means was tested using the "t" test at the 97.5% confidence level.

Table XI shows the results of this quadrant analysis with the number of comparisons made, the number and percent of comparisons in which the means were significantly different, and the quadrants where significant differences were found.

As would be expected, the B-3 has the greatest percentage of significant differences, probably because of the tendency for a coarse mix such as this to segregate. This tendency is also reflected in the higher percentage of significant differences for the coarser screens and the asphalt content. An observation that has not been explained is the greater relative significant differences associated with the A quadrant. No technological reasons can be offered for this behavior.

TABLE XI

QUADRANT ANALYSIS

Mix Type	Sieve Size	Comparisons	Significant	Percent Significant	QUADRANTS					
					AB	AC	AD	BC	BD	CD
B-3	3/4"	103	8	7.7	1	2	2	0	2	1
	#4	103	7	6.7	2	2	1	1	0	1
	#8	103	5	4.8	3	1	1	0	0	0
	#200	103	4	3.8	1	1	1	0	1	0
	A.C	103	10	9.7	2	3	3	0	2	0
	Total	618	34	5.5	9	9	8	1	5	2
I-2	3/8"	18	0	0.0	0	0	0	0	0	0
	#4	60	0	0.0	0	0	0	0	0	0
	#8	18	0	0.0	0	0	0	0	0	0
	#50	66	2	3.0	1	1	0	0	0	0
	#200	66	1	1.5	1	0	0	0	0	0
	A.C.	66	1	1.5	1	0	0	0	0	0
	Total	294	4	1.3	3	1	0	0	0	0
S-5	3/8"	84	1	1.1	0	0	0	0	0	1
	#4	84	0	0.0	0					
	#8	84	1	1.1	0		1			
	#30	84	1	1.1				1		
	#50	84	2	2.2	1	1				
	#200	84	0	0.0						
	A.C.	84	3	3.3			1		2	
	Total	588	8	1.3	1	1	2	1	2	1

CONCLUSIONS

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The most important conclusions resulting from this study are:

1. The 1970 bituminous concrete production is consistent with that of 1967, on which the present statistical specification is based.

2. The range method can predict standard deviations accurately and can be used on a lot to lot basis.

3. There is no consistent trend for standard deviation with length of plant operation.

4. Even with the small number of continuous plants analyzed, it appears that, by and large, they do not produce as consistent a product as do batch plants.

5. There are not many significant differences from quadrant to quadrant within trucks for any plant, but most of the differences that do occur are found, as expected, in B-3 mixes.

6. The present tolerances are working well, but there are areas where improvements are possible, as noted under Recommendations for Tolerance Changes.

   (a) The tolerance for the average of four samples should be:

      (1) increased on the #4 sieve,

      (2) decreased on the $\frac{3}{4}$", $\frac{3}{8}$", #30, and #50 sieves, and for asphalt content.

   (b) The standard deviations should be made consistent and decreased for the #30, #50, and #200 sieves.

RECOMMENDATIONS FOR TOLERANCE CHANGES

Tolerances Relating to Job Mix Average

It would seem that the tolerances should be fairly consistent from sieve to sieve. Even if some properties are more critical than others, necessary adjustments should be made elsewhere.

Table XII, which is based on data from Tables II, III, and IV, was constructed to indicate the overall effect of a tolerance change on all mix types since it is felt unnecessary to have separate tolerances for different mix types. Revisions are suggested in the $\frac{3}{4}$", $\frac{3}{8}$", No. 4, No. 30, and No. 50 sieves and in the asphalt content. All of the changes are slight: 0.5% in the sieves and 0.1% for the asphalt content. However, with these changes the tolerances are much more uniform from sieve to sieve.

TABLE XII

SUGGESTED CHANGES IN TOLERANCES FOR AVERAGES OF 4 SAMPLES

Sieve		Specification			Percent of Projects Above Tolerance								
					B - 3			I - 2			S - S		
		J M - $\overline{X}$	S	Total	J M-$\overline{X}$	S	Total	J M-$\overline{X}$	S	Total	J M-$\overline{X}$	S	Total
$\frac{3}{4}$"	O*	2.00	3.50	5.50	31.2	15.6	18.7						
	SR**	1.50	3.50	5.00	43.8	15.6	25.0						
$\frac{3}{8}$"	O	2.00	3.50	5.50				30.0	40.0	40.0	28.9	5.3	2.6
	SR	1.50	3.50	5.00				30.0	40.0	40.0	44.7	5.3	5.3
No. 4	O	1.50	3.00	4.50	56.2	43.8	53.1	41.0	35.9	30.8	50.0	36.8	52.6
	SR	2.00	3.00	5.00	41.0	43.8	34.4	33.3	35.9	23.1	44.7	36.8	39.5
No. 8	SR	1.50	3.00	4.50	34.3	25.0	31.2	60.0	20.0	30.0	36.2	40.0	38.3
No. 30	O	1.50	3.00	4.50							38.3	14.9	17.0
	SR	1.50	2.50	4.00							38.3	20.4	24.5
No. 50	O	1.00	2.00	3.00				52.5	5.0	17.5	31.6	18.4	15.8
	SR	1.00	1.50	2.50				52.5	12.5	27.5	31.6	28.9	28.9
No. 200	NC***	0.50	1.00	1.50	43.7	9.4	15.6	50.0	10.0	25.0	55.1	23.4	36.7
AC	O	0.25	0.25	0.50	3.2	28.1	9.4	17.5	27.5	25.0	12.8	34.0	14.8
	SR	0.15	0.25	0.40	22.6	28.1	10.4	35.0	27.5	30.0	31.2	34.0	25.0

* Original
** Suggested revision
*** No Change

Tolerances Relating to Total Variability

Table XIII presents the present initial adjustment values; i.e., the values at which the unit price paid for bituminous concrete is decreased. Also shown are the 1970 variability data and the total tolerances for means of four as recommended. Since it is felt that acceptable material would be produced under the total tolerances as shown in Table XIII, the suggested revisions for total variability were determined by selecting values for standard deviations slightly less than the total tolerances. This approach, in effect, assumes the total tolerances are acceptable regardless of whether they are based on simply two standard errors, or two smaller standard errors plus a job mix-production average difference.

TABLE XIII

SUGGESTED REVISIONS IN TOLERANCES FOR TOTAL VARIABILITY

Sieve Size	Present Initial Adjustment Values	1970 Variability Data			Total Tolerance	Suggested Revisions
		B-3	I-2	S-5		
¾"	4.6%	2.8 %			5.00	4.6 %
⅜"	4.6		3.3 %	1.4 %	5.00	4.6
#4	4.6	2.9	2.7	2.9	5.00	4.6
#8	4.1	2.5	2.2	2.8	4.50	4.1
#30	4.1			1.9	4.00	3.6
#50	3.1		1.2	1.3	2.50	2.1
#200	2.1	0.6	0.6	0.8	1.50	1.6
A. C.	0.33	0.22	0.24	0.22	0.40	0.33

REFERENCES

1. Dillard, J. H., "Implications of Several Types of Statistical Specifications," Virginia Highway Research Council, February 1966.

2. ______________, "Field Experiment with Statistical Methods," Virginia Highway Research Council, September 1968.

3. Maupin, G. W., Jr., "Standard Deviation and Arithmetic Mean of Asphalt Content in Typical Virginia Asphalt Plants," Virginia Highway Research Council, June 1966.

APPENDICES

Revised 4-1-71

VIRGINIA DEPARTMENT OF HIGHWAYS
SPECIAL PROVISIONS
FOR SECTION 212 BITUMINOUS CONCRETE
(STATISTICAL QUALITY CONTROL SPECIFICATION)

Bituminous concrete on this contract shall be furnished in accordance with the applicable Sections of the 1970 Specifications as amended hereinbelow:

Section 212.03 is completely replaced by the following:

Sec.212.03 Job-Mix Formula - The Contractor shall submit, for the Engineer's approval, a job-mix formula for each mixture to be supplied for the project prior to starting work. The job-mix formula shall be within the design range specified in Table VIII, Bituminous Concrete Mixtures (see attached) for the particular type of bituminous concrete specified. The job-mix formula shall establish a single percentage of aggregate passing each required sieve size, a single percentage of bituminous material to be added to the aggregate and a single temperature at which the mixture is to be produced. The job-mix formula for each mixture shall be in effect until modified in writing by the Engineer.

Materials from more than one source shall not be used alternately, nor mixed when used in surface courses without the written consent of the Engineer. Where additional sources of materials are approved, a job-mix formula shall be established and approved before the new material is used. When unsatisfactory results or other conditions make it necessary, the Contractor shall prepare and submit a new job-mix formula for approval. Approximately one week may be required for the evaluation of a new job-mix formula.

The Marshall design density of a mixture shall not exceed 98.0 percent of the theoretical maximum density. In the event Marshall densities begin to exceed 98 percent of theoretical maximum density during construction the Contractor shall alter the grading of the aggregate or otherwise shall obtain his aggregate from a different source.

Section 212.06 is completely replaced by the following:

Sec.212.06 Plant Inspection - The preparation of all bituminous mixtures shall be subject to inspection at the plant. For this purpose the Contractor shall provide a suitable building to be used as a field laboratory in accordance with requirements of Supplemental Specifications for Section 517. The Contractor shall furnish, maintain and replace as condition necessitates, the following testing equipment:

* 2 - reflux extractors (2000 gram capacity)
* 2 - electric hot plates (thermostatically controlled) suitable for use with the above reflux extractors
1 - beam-type balance meeting the following minimum requirements:
  (a) Capacity - Not less than 2000 grams
  (b) Dial - "Over" and "under" with center mark
  (c) Beam - 12 inch minimum length, 100 gram capacity, notched in increments of 1 gram, with hanging and self-locking poise counterweight
1 - set of graduated gram weights
1 - electric hot plate or oven for drying sample (temperature range to at least 300°F)
1 - mechanical sieve shaker
1 - set of sieves (2" through #200 mesh)
1 - separator for separating the plus and minus 3/4 inch material for bituminous concrete base courses (Minimum dimensions of 3/4 inch sieve shall be 12 inches by 12 inches.)
1 - set of milk scales

* One additional reflux extractor and one additional electric hot plate shall be furnished for each 1000 tons of material produced per day in excess of 2000 tons except when a lot size of 4000 tons is used.

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(Continued)

Miscellaneous supplies - pans, brushes, scoops or large spoons, several 1000 ml. graduated beakers and an adequate supply of running water, which is not to exceed 80°F in temperature, shall be provided.

The above mentioned equipment shall be installed ready for operation in a field laboratory meeting the requirements of Supplemental Specifications for Section 517. Additionally, the building shall be adequately ventilated by exhaust fan.

The requirements stated hereinabove shall not be construed as a nullification of the requirements of Sections 106.05 and 200.01.

The Department's representative shall have ready access to all parts of the plant for checking the accuracy of the equipment in use, inspecting the condition and operation of the plant and for any purpose in connection with the materials and their processing.

Section 212.29 is added as follows:

Sec.212.29 Acceptance - Sampling for determination of gradation and asphalt content will be performed at the plant, and no further sampling will be performed for these properties. However, should visual examination reveal that the material in any batch or load is obviously contaminated, deficient in asphalt content or not thoroughly mixed, that batch or load will be rejected without additional sampling or testing of the lot. In the event it is necessary to determine, quantitatively, the quality of the material in an individual batch or load, one sample (taken from the batch or load) will be tested and the results compared to the "process tolerance for one test" as described hereinbelow. The results obtained in the testing of a specific individual batch or load will apply only to the batch or load in question. Gradation and asphalt content determinations will be performed in the plant laboratory furnished by the Contractor; however, the Department reserves the right to discontinue the use of the plant laboratory for acceptance testing in the event of mechanical malfunctions in the laboratory equipment and in cases of emergency involving plant inspection personnel. In the event of such malfunctions or emergencies, acceptance testing will be performed at the District or Central Office laboratory until the malfunction or emergency has been satisfactorily corrected or resolved.

Acceptance for gradation and asphalt content will be based upon a mean of the results of four tests performed on samples taken in a stratified random manner from each 2000 ton lot (4000 ton lot when the contract item is in excess of 50,000 tons). A lot will be considered to be acceptable for gradation and asphalt content if the mean of the results obtained from the four tests fall within the following process tolerances allowed for deviation from the job-mix formula:

Sieve	Process Tolerance % Passing
Top Size	± 0.0
1½"	5.5
3/4"	5.5
1/2"	5.5
3/8"	5.5
#4	4.5
#8	4.5
#30	4.5
#50	3.0
#200	1.5
Asphalt Content*	0.5

* Asphalt content will be measured as extractable asphalt.

Size & A.C.	Standard Deviation		
	1 adjustment point for each sieve size & A.C.	2 adjustment points for each sieve size & A.C.	3 adjustment points for each sieve size & A.C.
1½"	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
3/4"	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
1/2"	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
3/8"	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
#4	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
#8	4.1 - 5.0	5.1 - 6.0	6.1 - 7.0
#30	4.1 - 5.0	5.1 - 6.0	6.1 - 7.0
#50	3.1 - 4.0	4.1 - 5.0	5.1 - 6.0
#200	2.1 - 3.0	3.1 - 4.0	4.1 - 5.0
A.C.	0.33 - 0.42	0.43 - 0.52	0.53 - 0.62

The unit bid price shall be reduced by 0.5% for each adjustment point applied.

The disposition of material having standard deviations larger than those shown in the table, shall be determined by the Engineer.

Section 212.31 is added as follows:

Sec.212.31 Referee System -

(a) In the event the test results obtained from one of the four samples taken to evaluate a particular lot do not appear to be representative, the Contractor or the Engineer may request that the results of the questionable sample be disregarded; whereupon, tests will be performed on five additional samples taken from randomly selected locations in the roadway where the lot was placed. The test results of the three original (unquestioned) samples will be averaged with the test results of the five road samples and the mean of the test values obtained for the eight samples will be compared to the following process tolerance:

$$\text{Process tolerance for mean of eight tests} = \frac{\text{Process tolerance for mean of four tests}}{1.4}$$

(b) In the event the Contractor elects to question the mean of the four original test results obtained for a particular lot, he may request additional testing of that lot. Upon receipt of written request for additonal testing, the Department will test four samples taken from randomly selected locations in the roadway where the lot was placed. The test results of the original four samples will be averaged with the test results of the four additional road samples and the mean of the test values obtained for the eight samples will be compared to the "process tolerance for mean of eight tests" as described hereinabove.

In the event the mean of the test values obtained for the eight samples is within the process tolerance for the mean of the results of eight tests, the material will be considered acceptable. In the event the mean of the test values obtained for the eight samples is outside of the process tolerance for the mean of the results of eight tests, the lot will be adjusted in accordance with the adjustment rate specified hereinabove.

Additional tests, requested by the Contractor under the provisions of Section 212.31(a) and (b), will be paid for by the Contractor in the event the mean of the test values obtained for the eight samples falls outside of the process tolerances. Such additional tests shall be paid for at a rate of five times the bid price per ton of material per sample.

TABLE VIII

BITUMINOUS CONCRETE MIXTURES

(Design Range)

Type	Percentage by Weight Passing Square Mesh Sieves *											Percent Bitumen	Mix Temperature (At Plant)
	2	1-1/2	1	3/4	1/2	3/8	No.4	No.8	No.30	No.50	No.200		
S-1							100	94-100	69-77	38-49	2-6	8.5 - 10.5	245 - 280°F
S-2						100	91-100	69-77	26-34	16-24	4-8	9.5 - 12.0	245 - 280°F
S-3						100	88-100	79-87	36-44	21-29	5-9	6.5 - 10.5	210 - 220°F
S-4					100	88-100	76-90	66-74	31-39	16-24	4-8	5.5 - 9.5	245 - 280°F
S-5					100	83-97	53-67	41-49	19-27	11-19	4-8	5.0 - 8.5	245 - 280°F
I-1			100	88-100		86-100	81-95	74-82	39-47	20-28	4-8	5.0 - 7.5	245 - 280°F
I-2			100	95-100		63-77	43-57	31-39		6-14	2-6	4.5 - 8.0	245 - 280°F
B-1			100	88-100			78-92	71-79	41-49	22-30	2-6	3.0 - 6.5	245 - 280°F
B-2		100		56-70			21-35	16-24			1-5	4.0 - 6.0	210 - 220°F
B-3		100		73-85			38-48	28-35			2-6	4.0 - 7.0	245 - 280°F
B-4	100	88-100		78-92			51-65	44-52	26-34		5-13	2.5 - 4.0	245 - 280°F
P-1						100	86-100	76-84	36-44	21-29	5-7	6.5 - 9.5	145 - 155°F
P-2					100	83-97	53-67	41-49	19-27	9-17	4-8	6.5 - 8.5	145 - 155°F
P-3				100		63-77	38-52	24-32			1-5	5.5 - 7.5	145 - 155°F

* In inches, except where otherwise indicated. Numbered sieves are those of the U. S. Standard Sieve Series.

APPENDIX B

TL-100 DATA MIX

VIRGINIA DEPARTMENT OF HIGHWAYS
MATERIALS DIVISION
BITUMINOUS PLANT INSPECTORS REPORT

RT. ________ PROJ. ________
B.P.R NO ________
COUNTY ________
MAINT. SCHEDULE ________
DATE ________

MATERIAL (TYPE MIX) ________ INSPECTOR'S REPORT NO (LOT NO) ________
MFD. BY ________ AT ________
CONSG'D TO ________ AT ________
TYPE OF PLANT ________ MIX. TIME PER BATCH ____ DRY / ____ WET SEC.

MATERIALS

	KIND	%	SOURCE	CAR NUMBER	DATE RECEIVED	SEAL NO.
ASPHALT						

				SIEVE										
				-2"	-1½"	-1"	-¾"	-½"	-⅜"	-4	-8	-30	-50	-200
AGGREGATE														

BIN ANALYSIS OF AGGREGATE

BIN NO.	-2"	-1½"	-1"	-¾"	-½"	-⅜"	-4	-8	-30	-50	-200	
1												
2												
3												
4												

BATCH WEIGHTS

	BIN NO. 1	BIN NO. 2	BIN NO. 3	BIN NO. 4	FILLER	ASPHALT	TOTAL

ANALYSIS OF MIXTURES

SAMPLE/TON	HOUR	TEMP.	DATE										AC
1( )													
2( )													
3( )													
4( )													
AVERAGE													
ACC. RANGE													
JOB MIX	—		—										

HOURLY TEMPERATURES OF MIXTURES

TIME																								
TEMPERATURE																								
DATE																								

DATE	AIR TEMP.	
	AM	PM

DATE	DENSITY

PRODUCTION (MATERIAL ________)	ASPHALT CEMENT
TONS PREVIOUS ________	________
TONS THIS REPORT ________	________
TOTAL ________	________

________ INSPECTOR
________ ADDRESS
LAB NO. BM ________

REMARKS: PASS ________ FAIL ________
☐ LOT TO BE PENALIZED ____%
☐ LOT TO BE REMOVED FROM ROAD
MATERIAL PLACED FROM STA. ______ TO STA. ______

(SIGNATURE) ________
DISTRICT MATERIALS ENGINEER

APPENDIX C

DESIGNATION OF TRUCK QUADRANTS

The present statistical sampling plan calls for a stratified random selection of four samples from each 2,000 tons produced. One sample is drawn from each 500 tons. For each sample both the ton and quadrant of the truck from which the sample is taken is randomly selected. Quadrant is pictorially presented below.