Construction Industry Response to a Statistically Based Bituminous Concrete Specification in New Jersey

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The evolution of a statistically based specification for bituminous mix in New Jersey is reviewed. How five producers of asphalt mix dealt with the specification and their various attitudes and approaches toward design and quality control are discussed. An overview is presented of studies by the New Jersey Department of Transportation of projects run under the specification. Particular problems with the specification encountered by both the producer and the state are cited. Revisions to the specification that were used in an effort to correct the various problems are outlined. Finally, a critique is given of the specification as it evolved and as it stands today.

Before 1968, virtually all bituminous mix design and testing in New Jersey was performed by state highway department personnel. The 1961 Standard Specification for Road and Bridge Construction was still the basic specification in use. The salient provision of this specification related to bituminous concrete (specifications cited in this paper refer to U.S. customary units of measurement; therefore, no SI equivalents are given):

Formula for Job Mix. The composition limits for every mixture as prescribed in [Table 1] are extreme ranges that must not be exceeded.

The Laboratory will establish a job mix formula for each mixture to be supplied for the Project. The job mix formula shall be in effect until modified by the Laboratory. The job mix formula for each mixture shall establish a single definite percentage of mineral aggregate to be weighed from each bin, a single definite percentage of bituminous material to be added to the aggregate, the percentage or amount of any other ingredient that may be required, and the temperature at which the mixture is to leave the plant, all within the ranges of the specifications for the specific type of mixture. Should a change in sources of materials be made, a new job mix formula may be established before the mixture containing the new materials is produced.

After the job mix formula was established for a mixture as prescribed in Table 1, all mixtures of that type furnished for the project were to conform within the following tolerances:

Material	Tolerance (%)
Coarse aggregate, bottom course (total retained on no. 10 sieve)	±5
Coarse aggregate, top course (total retained on no. 10 sieve)	±4
Bitumen content for type SA top course	±0.5

Essentially, the producer was required to manufacture a mix that conformed to the master range of the gradation table and an asphalt content within a specified tolerance of design. With the exception of the bituminous stabilized base course, no Marshall testing was specified for any mix. All acceptance testing (and most quality control testing) was performed by state highway personnel.

In 1967 several factors were operating to move the New Jersey Department of Transportation (DOT) to revise their bituminous concrete specifications. From the viewpoint of industry, there was concern about the specifications for raw aggregate. It was felt that the fine aggregate requirement not only was difficult to meet (thus limiting sources of supply) but also contributed to unstable mixes. The coarse aggregates that were specified on the basis of percentage retained through sieves with round openings were also often difficult to obtain. In addition, the state's northern producers, who were involved with several different agencies (e.g., New York State, New York City, port authority), wanted to obtain a more standardized specification.

From the viewpoint of the state DOT, there was growing concern about the legal position in relation to projects in which material was found to be defective. Since personnel of the department had been responsible for both the design and quality control of the mixes, the department could not be considered totally free of responsibility should the material not meet specifications. There was also a desire to adopt a more standardized specification consistent with the national trend at that time.

It was in this atmosphere that the first "Addenda A" (revision to the standard specification for bituminous concrete) was conceived. The department felt that the specification should contain the following basic provisions:

1. A shift of responsibility for design and quality control of mixes from the state DOT to the producer,
2. Partial end-result specification in that there would be no gradation requirement for raw aggregates or hot bins at the plant so long as the producer could meet the finished mix parameters,
3. A more standardized specification basically molded after ASTM D 1663-67,
4. A reduced payment schedule for material deemed not in conformance with minimum performance requirements, and
5. Statistically based sampling and testing concepts that would provide some solid basis for item 4 above.

The producers were in favor of the first three items but not the last two. In January of 1968, the department published an interim revision that incorporated the first three concepts. This interim specification, termed "pink Addenda A," could be used as an alternate during this period by any producer who opted to do so.

The initial reaction of most producers to pink Addenda A was favorable. Although some added costs were incurred for mix design and quality control services, most felt that this was more than offset by the use of other, less costly raw materials and the ability to design and control their own mixes. The first adverse reaction on the part of the producer did not come until after the publishing of the November 1968 revision of Addenda A, which was the first statistically based specification (incorporating the last two provisions in the list above). From this time on, the Addenda A specification was

Table 1. Requirements for hot-mixed bituminous concrete and sheet asphalt from 1961 specifications.

Total Aggregate		Percentage by Weight						
Passing	Retained On	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7
Screen, in	Screen, in							
1.5	1	0-35	0-25					
1	0.5	25-70	20-45	8-25	0-10	0-5		
0.5	0.75	0-20	10-25	20-45	12-40	20-35	0-10	
	Sieve							
0.75	No. 10	0-15	5-15	5-25	8-30	15-30	8-25	0-5
Sieve								
No. 10	No. 30	1-11	2-14	2-14	2-17	8-22	3-20	4-25
No. 30	No. 50	2-15	5-18	5-18	4-24	4-15	8-30	10-35
No. 50	No. 80	2-14	4-18	4-18	6-22	3-15	10-28	12-33
No. 200		0-5	4-8	4-8	4-8	4-8	4-10	10-15
Total retained on no. 10 sieve		55-85	45-65	45-65	30-60	40-55	15-30	0-5
Bitumen content (solubility in benzol)		4-6	5-7	5-8	5.5-9	5-8	8-11	9-11.5

Notes: All screens 0.75 in and larger are round openings.
Aggregate to be used for the following pavement courses: mix 1—all bottom courses; mix 2—CA-BC-1, CA-BC-2, top; mix 3—MA-BC-1, MA-BC-2, top; mix 4—FA-BC-1, FA-BC-2, top; mix 5—SM-1, SM-2, top; mix 6—SP-1, SP-2, top; and mix 7—SA, top.

viewed with disdain and skepticism by many producers.

The pertinent provision of the November 1968 Addenda A can be found in Figure 1. Essentially, it calls for a lot of five samples to be taken for each 1500 tons of finished mix. A random number table was used to select the precise ton that was to be sampled in each sublot of 300 tons. Five quality parameters were selected for evaluating samples of mixtures taken at the plant. Three parameters were concerned with gradation, one with asphalt content, and the last with Marshall stability. The sixth parameter involved air voids, which were determined by using core samples taken from the finished pavement. The producer had to have a quality control technician present during all productions for state projects.

Tables of tolerances for gradation and asphalt content were included based on statistical analysis of central laboratory extraction data (primarily of road cores dating back to 1961). The tolerances in the first table were based on two standard deviations. This was applicable to single samples and was intended to control the range between individual samples in the lot. The tolerances in the second table were based on one standard deviation and applicable to the lot average.

Under this specification, there were two sets of requirements for the Marshall properties: First, a minimum stability was required for mix designs; second, a lower "control" standard was specified for a set of three specimens molded at the producer's laboratory from a material used for one of the five composition samples in a lot. For air voids, a wider range was again used for control than for design. In this case the control air-void requirement was applicable to individual cores taken for approximately every 2000 yd^2 of pavement.

In line with the department's concern about enforcement of the new specifications, provisions for payment reduction were incorporated for the five parameters to encourage producers to make every effort to comply. The November 1968 revision was a substantial change, then, from the standard 1961 specifications. Even though the rate of sampling and the tolerances had remained about the same, the shifting of responsibility for design and quality control, the increase in the number of parameters, and the inclusion of Marshall property requirements made the transition somewhat involved and difficult.

In 1968, very few producers had quality control personnel. With this in mind, the New Jersey DOT and the New Jersey Asphalt Paving Association jointly contracted with a consultant to give a 2-week course on mix design and quality control of asphalt pavement. This program was first held in February 1968 and was attended equally by both department personnel and employees of producers. Many other producers hired outside consultants to do their mix designs and quality control work. Very little if any in-house design or quality control of asphalt mixes was carried on by the producers before the new specifications were issued. Virtually all endeavors at a statistically based quality control program were a direct result of the requirements of the new specifications. All parties concerned were novices at this time, and much of the work was done by the trial-and-error method.

The response of five producers to the new specifications is detailed below. They are intended to be a fairly representative cross section of New Jersey producers.

PRODUCER A

Located in north-central New Jersey, producer A owns four asphalt plants in two locations and one quarry. Before 1968, there was one full-time quality control employee. His primary responsibility was the quarry and, although he performed some limited control on the asphalt mixes, the majority of this activity was taken care of by the state inspector. After 1968, one additional quality control person was hired.

Mix designs formulated by the quality control personnel represented basically the same mixes as those used under the old specifications. Because of a high rate of production and therefore of sampling, the technician had little time to do anything except acceptance testing. Raw aggregate or hot-bin gradation data were not normally collected—only the information required by the specification. The only additional test run was for "stone content," which consists of soaking the hot mix in gasoline, burning off the asphalt cement, and running a gradation on the stone retained above the no. 8 sieve. This test was used with some regularity as a quick check on the mix gradation. Only one specification parameter (amount passing the no. 8 sieve) could be checked by means of this test. No graph or chart of data was used. Most control was based on single extraction samples taken within a lot. In many cases, an entire lot of material—i.e., 1360 Mg (1500 tons)—would be produced in 1 d. Since the New Jersey DOT extraction test procedures were more involved than normal (requiring that the gradation on the aggregate after extraction be a washed gradation, which usually adds approximately 1 h to the normal test time), a competent technician could not normally be expected to run more than five extractions in an 8-h day. This meant that there was no time for additional quality control testing and therefore control judgments had to be based on acceptance samples.

Figure 1. Provision of November 1968 Addenda A revision to specifications for bituminous concrete.

GRADATION MIX NO.	1	2	3	4	5	6	7
SIEVE SIZE	GRADING OF TOTAL AGGREGATE (COARSE PLUS FINE, PLUS FILLER IF REQUIRED). AMOUNTS FINER THAN EACH LABORATORY SIEVE (SQUARE OPENING), WEIGHT PERCENT.						
2"	100	---	---	---	---	---	---
1-½"	90-100	100	---	---	---	---	---
1"	---	90-100	100	---	---	---	---
3/4"	60-100	---	90-100	100	---	---	---
1/2"	---	60-80	---	90-100	100	---	---
3/8"	---	---	60-80	---	90-100	100	---
No. 4	25-60	25-60	35-65	45-70	60-80	80-100	100
No. 8	20-50	15-45	20-50	25-55	35-65	65-100	95-100
No. 16	---	---	---	---	---	40-80	85-100
No. 30	---	---	---	---	---	20-65	70-95
No. 50	8-30	3-18	5-20	5-20	6-25	7-40	45-75
No. 100	---	---	---	---	---	5-20	20-40
No. 200	4-12	1-7	4-10	4-10	4-10	4-10	9-20
	ASPHALT CEMENT, WEIGHT PERCENT OF TOTAL MIXTURES						
	3.5-8	4-8.5	4-9	4.5-9.5	5-10	7-12	8.5-12

Formula for job mix. The Contractor shall submit for the Engineer's approval on forms supplied by the department, a job mix formula for each mixture required for the project, a statement naming the source of each component, and a report showing the results of the applicable tests specified in a table 3-B. The job mix formula, including the tolerances shown in table 3-A(1), shall be within the master range specified in table 3 for the particular type of bituminous concrete.

TABLE 3-A(1) TOLERANCES FROM JOB MIX FORMULA FOR INDIVIDUAL SAMPLES

GRADATION MIX NO.	1	2	3	4	5	6	7
SIEVE SIZE	TOLERANCE (PLUS OR MINUS) PERCENTAGES						
No. 8	8	6	5	5	5	8	-
No. 50	5	4	4	4	4	4	8
No. 200	2.0	2.0	2.0	2.0	2.0	2.0	2.0
ASPHALT	.6	.6	.5	.5	.5	.5	.5

TABLE 3-A(5) TOLERANCES FROM JOB MIX FORMULA FOR AVERAGE OF 5 SAMPLES

GRADATION MIX NO.	1	2	3	4	5	6	7
SIEVE SIZE	TOLERANCES (PLUS OR MINUS) PERCENTAGE						
No. 8	4.0	3.0	2.5	2.5	2.5	4.0	
No. 50	2.5	2.0	2.0	2.0	2.0	2.0	2.0
No. 200	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ASPHALT	.30	.30	.25	.25	.25	.25	.25

TABLE 3-B. DESIGN AND CONTROL REQUIREMENTS

MIX NUMBER	1 STONE	1 GRAVEL	2	3	4	5	6	7
CRITERIA	TEST LIMITS							
DESIGN STABILITY, LBS. MIN.	1500	1100	1200	1400	1300	1200	---	---
CONTROL STABILITY, LBS. MIN.	1200	800	900	1100	1000	900	---	---
FLOW VALUE .01	6-18	6-18	6-18	6-16	6-16	6-16	---	---
DESIGN AIR VOIDS % (NOTE 2)	3-7	3-7	3-7	3-6	3-6	3-6	3-8	3-6
CONTROL AIR VOIDS PERCENTAGE (NOTES 1 AND 2)	2-10	2-10	2-10	2-10	2-10	2-10	2-12	2-10

FOR ANY LOT OF BITUMINOUS CONCRETE WHICH IS NECESSARILY LESS THAN 1500 TONS, THE TEST RESULTS OF THE INDIVIDUAL SAMPLES SHALL CONFORM TO THE JOB MIX FORMULA WITHIN THE TOLERANCES OF TABLE 3-A(1). WHEN ANY SUCH LOT DOES NOT COMPLY WITH THIS REQUIREMENT, THE PAYMENT QUANTITY FOR THAT LOT SHALL BE REDUCED BY 5%.

TABLE 3-C 5-SAMPLE AVERAGES

DEVIATION OF 5-SAMPLE AVERAGE, PERCENT OF TOLERANCES IN TABLE 3-A(5)	REDUCTION OF PAYMENT QUANTITY PER LOT, PERCENT
0 to 100	NONE
101 to 150	5
151 to 200	10
OVER 200 (See Note 2)	15

NOTE 1 - WHERE MORE THAN ONE ADJUSTMENT OF PAYMENT QUANTITIES FROM THE ABOVE TABLES IS APPLICABLE TO A LOT, USE ONLY THE GREATEST SINGLE ADJUSTMENT FOR NON-CONFORMANCE TO THE JOB-MIX FORMULA.

NOTE 2 - THE ENGINEER MAY ORDER THE REMOVAL, AT THE CONTRACTOR'S EXPENSE, OF ANY MATERIAL SUBJECT TO THE MAXIMUM ADJUSTMENT OF PAYMENT QUANTITY SHOWN IN TABLE 3-C.

CONFORMANCE TO THE CONTROL STABILITY REQUIREMENTS SPECIFIED IN TABLE 3-B SHALL BE ASCERTAINED FROM ONE STABILITY DETERMINATION FOR EACH LOT OF MATERIAL. THE MATERIAL FOR THE STABILITY DETERMINATION SHALL BE OBTAINED AT THE MIXING PLANT AT THE SAME TIME THAT ONE OF THE RANDOM SAMPLES IS TAKEN.

TABLE 3-D ADJUSTMENT OF PAYMENT QUANTITIES PER LOT OF BITUMINOUS CONCRETE DUE TO NONCONFORMANCE TO STABILITY REQUIREMENTS.

DEVIATION OF LOT STABILITY BELOW CONTROL STABILITY OF TABLE 3-B (LBS)	REDUCTION OF PAYMENT QUANTITY (PERCENT)
0 to 100	5
101 to 200	10
OVER 200	20

CONFORMANCE TO THE CONTROL AIR VOIDS SPECIFIED IN TABLE 3-B SHALL BE DETERMINED ON THE BASIS OF ONE AIR VOIDS MEASUREMENT FOR EACH LOT OF APPROXIMATELY 2000 SQUARE YARDS A SINGLE RANDOM CORE FROM THAT LOT.

TABLE 3-E

MIX NUMBER	DEVIATION OF LOT, ABOVE CONTROL AIR VOIDS (PERCENT)	DEVIATION OF LOT, BELOW CONTROL AIR VOIDS (PERCENT)	REDUCTION OF PAYMENT QUANTITY (PERCENT)
1 AND 2	0.0 to 0.7	- - - - - - - - -	5
	0.8 to 1.5	0.0 to 0.5	10
	OVER 1.5	OVER 0.5	20
3,4,5,6, and 7	0.0 to 1.0	- - - - - - - - -	5
	1.1 to 2.0	0.0 to 0.5	10
	OVER 2.0	OVER 0.5	20

PRODUCER B

Producer B is located in central New Jersey and has six hot-mix plants at three locations and two quarries. Before the new specifications, there was one quality control employee whose primary function was control of the quarry operations. In 1967, a new asphalt testing laboratory was constructed and, over the next 2 years, an additional four employees were hired. All state mixes at this time were produced with bank-run sand and quarried stone. Trial mix designs were set up based on the new specifications and used the unprocessed quarry screenings (stone sand). These mixes were used in all commercial work. Raw-aggregate, hot-bin, extraction, and Marshall data were collected. Standard deviations were developed for the commercial mixes in production. These deviations were beyond those set out in the November 1968 Addenda A. Efforts were made to correct this problem. Attempts were made to better control both the gradation and the feeding of raw materials at the plant. A more elaborate sampling technique was tried. A program to "reeducate" plant operators was begun. Emphasis was placed on consistent cold-feed control and improved methods of storing and handling raw aggregate. An automatic compactor and a larger extractor were purchased for the laboratory. As a result, the standard deviation was reduced in 1969, but material was still often found to be outside the limits of the new specifications.

PRODUCER C

Producer C is located in south-central New Jersey. They had three asphalt plants at two locations and a natural sand pit. They had no quality control employees; instead, all work was contracted out to a consultant. Thus, quality control work was performed only when the project required it. This producer ran one of the few large jobs [approximately 136 078 Mg (150 000 tons)] under the January 1968 Addenda A. A new 3.6-Mg (4-ton) plant and a new laboratory were built for this job. The mix designs were set up with quarried stone and bank-run sand from the producer's pit located adjacent to the mix plant. Since the only sampling specified at this time was one roadway core (for composition, thickness, and density) for every 3000 yd^2, the consultant set up his own sampling program at the plant as follows:

1. Minimum of one set of raw-aggregate gradation daily,
2. Minimum of one set of hot-bin gradation daily,
3. Minimum of two extractions daily, and
4. Minimum of two sets (three plugs) of Marshall specimen daily.

The daily rate of production for the plant was between 1089 and 1633 Mg (1200 and 1800 tons). The mix was considered under control if the results fell within the tolerance for individual samples. Since this earliest specification had no averaging or penalty provision, no consideration was given at this time to statistical control.

Three major problems became apparent as the job progressed. The first was a lack of management supervision of plant operation. A relatively inexperienced operator was left to manage the plant by himself. Cold-feed calibration settings were rarely followed. An unsupervised loader operator allowed cold-feed bins to run out of material. Little or no action was taken by the supervisor-dispatcher when quality control problems were reported. In one instance, the plant ran in an "out-of-control" situation with variable carryover of 12.7-mm (0.5-in) material in bin 4 for 3 d before the general superintendent appeared and discovered the hole between the bin 3 and bin 4 compartments. The state inspector was not concerned since he considered this an end-result specification in that cores taken from the road would have to fail before the material would be considered unacceptable.

The second problem to develop during the course of the job was the variability of the bank-run sand. Although some borings of the pit had been taken, either a rational mining plan was never established by the producer or the material was too inherently variable. The end result was high variability on all three of the acceptance sieves [2.36, 0.3, and 0.075 mm (no. 8, no. 50, and no. 200)] in the final mix.

The third problem concerned the metering of mineral filler into the mix. Either the filler delivery system was too large, or the electromechanical control was too coarse. In any case, sample-to-sample variance outside the 2.0 percent tolerance of the specification was common on the 0.075-mm (no. 200) sieve.

The variances on the 2.36- and 0.3-mm (no. 8 and no. 50) sieves were equally high. Initially, the consultant followed the standard procedures of "quartering" the mix sample to reduce it to testing size. When high variance was found on the 2.36-mm sieve, the "grab" method of sampling was tried simultaneously as an alternative. In this case, one pan of material was taken from the truck from three levels of conical pile by using small shovels. A grab sample was carefully taken from the pan in a large grain scoop. Then the same pan of material was quartered in the usual way, and another sample was taken. Extractions were run on both samples. Sample-to-sample variance on the 2.36-mm sieve for the grab samples was about half as great as that for the quartered sample.

Although the use of the grab method reduced the variance on the 2.36-mm sieve, samples would still fall outside the tolerance with some regularity. This was usually attributable to raw-aggregate and cold-feed variances that were well beyond the tolerances and in many cases out of control. At times, the bank-run sand would alternate over a range more than twice the tolerance during the course of a single day. Although efforts were made to monitor and control this material, it was often out of control.

Producer C had another, older plant located in their central yard that produced material under the November 1968 specifications during this period. This plant used a bank-run sand from another source and was under the direct supervision of the chief superintendent. During this same period, this plant produced material with a sample-to-sample variance on the 0.3- and 0.075-mm (no. 50 and no. 200) sieves about half that of the newer plant. The same consultant was used for mix design and quality control in both plants.

PRODUCER D

Located in the southern part of the state, producer D operated one asphalt plant and a natural sand pit. Before 1968, they had no quality control run on their material other than that performed by the state inspector. With the advent of the new specifications a consultant was hired to do the mix design and quality control work. The only time quality control testing was performed was when the plant was supplying a state project. The mix designs were very similar to those under the old specifications. The producer's own bank-run sand and a quarried stone and mineral filler were used. The same daily testing program established by the consultant for producer C was again implemented here. Since most

work for this plant came under the November 1968 revision of Addenda A (which included the statistical concepts), additional extractions were run on each lot sample. These extraction results soon became the primary data for quality control because of the penalty provision in the specifications. The problems encountered at this plant were twofold: first, the lack of respect for the quality control process on the part of the owners; and second, the variability of the bank-run sand. The owner would generally tell the batch man to run "light on filler and heavy on sand." The more expensive items in the mix in this case were filler and stone. This made effective quality control by the consultant quite difficult since no meaningful mix changes could be implemented until the owner was convinced it was necessary. Another common practice was to "top" trucks (i.e., mix only the final top loads in the truck according to design). On several occasions, the plant ran out of mineral filler and yet continued to ship material to the job. The bank-run sand, although fairly consistent, did tend to shift enough over time to require design revisions on the amount passing the 0.3-mm (no. 50) sieve.

PRODUCER E

Located in southeastern New Jersey, producer E operates one asphalt plant. Before 1968, this company had no quality control personnel. The mixes at this time were designed with natural sand, which was readily available. With the coming of Addenda A, a consultant was hired for the design and quality control work. In this case, the owner and plant superintendent took a strong interest in the quality control program. Suggestions made by the consultant were acted on promptly. Yard personnel and operators were given an understanding of what the quality program was about and materials were purchased with some consideration as to their quality.

Basically, the same quality control program outlined previously for producer C was again used here. In this case, control charts were used for the raw materials and mix analysis. A desired range for the raw materials was established based on the mix design and, when trends outside the range became apparent, calls were made to the suppliers to correct the problem. As deviations from the job-mix mean became apparent, small adjustments were made in the mix formula.

The only serious problem the consultant found was in the variance between the field and the central laboratory. In one instance, when the central laboratory reported a lot failure, the consultant witnessed the running of the "referee" sample at the central laboratory. Under this system, the mix sample was divided at the plant into three portions. The first went to the central laboratory for analysis and was considered the sample of record. The second was run by the producer's quality control person at the plant. The third was tagged, sealed, and stored as a referee sample.

The central laboratory had a policy of running only one ash correction per lot of material on their centrifuge extraction. When ash corrections were run on all samples in the lot, all passed and conformed fairly closely with the results obtained at the plant.

This producer succeeded in running several medium-sized [36 360-Mg (40 000-ton)] jobs without penalties under the new specification.

SUMMARY OF 1968-1970 PERIOD

In summary, it seemed that during this period only a few producers fully comprehended the ramifications of the new specifications and most felt they could get by without any changes in their basic operations. Quality control data were generally viewed with skepticism by the few producers who could comprehend it. Generally speaking, the few comprehensive quality control programs (those including raw-aggregate and hot-bin data and regular visual plant inspection) fell prey to the demands of the end-result process. The extraction sample of record (and, to a lesser degree, the Marshall sample) became the dominant indicator of mix quality. In the beginning, there was generally a poor understanding at the field level of the statistically based two-tolerance system. Most quality control personnel soon realized that mixes had to be controlled on the lot tolerance (average of five) and not on the individual tolerances.

Extractions run in the field were often considered acceptable if they fell within the tolerance for individual samples (which was twice as wide as that for the lot average). On several early jobs it seemed that passing results were being obtained, but at the end of those jobs it was found that the lot failed on the basis of the average of five.

In spite of this, few if any charts were kept of process control data. In fact, when the department distributed control charts in 1970 and required their use, there was so much resistance on the part of both producers and state personnel that the program faded out of existence a year later. The only significant collecting and publishing of data were done by the department in the job printout, an example page of which is shown in Figure 2. Most process control continued to be based on the variances of the individual samples in a lot. Technicians generally reviewed the individual sample result and made "judgment calls" as to whether the formula needed to be adjusted. Depending on the technician, these judgment calls may have been based on overall plant operations (variance in raw aggregate and screening problems) or simply the results of the last extractions.

In late 1969, the New Jersey DOT did a study of projects completed under the new specification (1). It found that 17 of the 35 lots included in the study failed to comply and were subject to penalties. Approximately 75 percent of the failures were for composition, and the remaining failures were equally divided between core air voids and Marshall stability. An evaluation of the average standard deviations for the projects showed that they were equal to or less than those used in developing the specification. Thus, the state concluded that excessive variance was not the cause of the failures but rather multilaboratory testing variance and the inability of the producer's quality control process to keep his process average target on the job mix. This was amply demonstrated by the fact that central laboratory results showed a consistent variation from producers' laboratory results on duplicate samples. At the same time, the producers' own results showed that they often failed to meet the average of five sample tolerances based on their own design. In the area of composition testing, most samples failed because they missed the target values and not because they were excessively variable. The state attributed this to the lack of experience of the producers' quality control personnel or "inexactness in the designing of the mix" or both.

From the producer's viewpoint, there appeared to be several problem areas with the new specification. First, there was the problem of the difference between the sample run at the plant laboratory, on which all quality control was based, and the sample run at the department's central laboratory, on which all payments were based. Next, there was the problem of adjusting the mix design for variations in raw materials. Under the 1968 Addenda A, the lengthy process of submitting a new design was the only method of making adjustments [this was partic-

Figure 2. Page from New Jersey Department of Transportation job printout.

10-29-69 NEW JERSEY STATE DEPARTMENT OF TRANSPORTATION PAGE 2
DIVISION OF MATERIALS
SIEVE ANALYSIS REPORT
BITUMINOUS MATERIALS

US 206(1953) SEC. 3A & 4A

CONTROL SECTION 324

MIXTURE FABC

LABORATORY SERIAL NUMBER	909724	909855	909856	909857	909858	
DATE LAID	6 -4-69	6 -5-69	6 -5-69	6 -5-69	6 -6-69	
CONTRACTOR	115	115	115	115	115	
PRODUCER	28	28	28	28	28	
SCREENS AND SIEVES USED	PERCENT					INDIVIDUAL SPEC TOLERANCE
PASSING 1/2 IN	100.0	100.0	100.0	100.0	100.0	100.0-100.0
PASSING 3/8 IN	98.0	98.0	98.0	94.0	95.0	90.0-100.0
PASSING NO. 4	74.0	75.0	75.0	65.0	63.0	60.0- 80.0
PASSING NO. 8	53.0*	52.0	55.0*	49.0	47.0	42.0- 52.0
PASSING NO. 50	21.0	20.0	24.0*	21.0	20.0	15.0- 23.0
PASSING NO.200	6.0	5.5	6.8	8.1*	5.4	3.4- 7.4
BITUMINOUS CONTENT	5.1	5.3	5.4	5.7	5.4	5.1- 6.1
LOT AND SAMPLE	1A	1B	1C	1D	1E	

* DENOTES FAILURE OF A PARTICULAR SAMPLE AT THAT PARTICULAR SCREEN SIZE INDICATED

DEVIATION IN THE SAME CHARACTERISTIC OF 2 OR MORE INDIVIDUAL SAMPLES-PASSING NO. 8
5 PERCENT REDUCTION

SCREENS & SIEVES USED	PERCENT					SAMPLE AVG.	SPEC TOLERANCE	AVG. TOLERANCE
PASSING NO. 8	53.0	52.0	55.0	49.0	47.0	51.20	2.50	44.50- 49.50
PASSING NO. 50	21.0	20.0	24.0	21.0	20.0	21.20	2.00	17.00- 21.00
PASSING NO.200	6.0	5.5	6.8	8,1	5.4	6.36	1.00	4.40- 6.40
BITUMINOUS CONTENT	5.1	5.3	5.4	5.7	5.4	5.38	0.25	5.35- 5.85

DEVIATION OF 5-SAMPLE AVG. PASSING NO. 8 10-PERCENT REDUCTION
DEVIATION OF 5-SAMPLE AVG. PASSING NO. 50 5-PERCENT REDUCTION

ularly applicable on the 0.3-mm (no. 50) sieve]. Next, there was a general feeling that the tolerances were not broad enough to contain normal variation, a desire to have more than just the three plugs per lot on the stability determination, and a desire for a modification in the basic gradation tables to allow the use of a wider variety of raw materials.

Shortly after the completion of the 1969 study, the department began to allow the acceptance of "retroactive designs." These could be submitted by the producer after he reviewed the lot data from the central laboratory. Retroactive designs could be submitted on a lot-to-lot basis and were intended to compensate for multilaboratory testing variance. This required nothing more than a letter requesting a numerical change on a particular sieve.

In September 1970, a new revision of the 1968 Addenda A was published. Known as the "yellow Addenda A," it contained the following revisions:

1. Changes in the basic gradation tables;
2. An increase in the gradation and asphalt cement (AC) tolerance for both the individual and average (in addition, the penalty provision for failing to comply with the individual sample tolerance was removed);
3. Plant acceptance, i.e., the final acceptance of material for gradation, AC content, and Marshall stability based on the plant technician's field results (these tests had to be carefully documented on forms supplied by the department and witnessed by the state inspector);
4. A tightening up of the air-void limits for both design and field core samples;
5. An increase in the number of specimens used for the Marshall stability criteria (one plug would be made and tested for each of the sublot samples, and the average of five would have to meet the minimum specified for control);
6. A reduction in the amount of the penalty for nonconformance; and
7. A limitation on the use of unwashed natural fine aggregates.

Also included in the yellow Addenda A was a detailed description of the various testing procedures to be followed.

The above changes seemed to resolve most of the problems that had plagued the first Addenda A. Although the policy of allowing retroactive design changes eliminated many composition penalties, the department was less than enthusiastic about this approach. It was felt that this policy encouraged an even greater lack of control by the producer. Thus, late in 1971, the department changed its policy and allowed design changes only at the beginning of a lot.

The inclusion of a natural sand requirement that effectively eliminated the use of bank-run sands disturbed most of the producers in the South Jersey area. The department's action was the result of several pavement failures attributed to clay "pop-outs" in mixes that used bank-run sand.

With the advent of "plant acceptance," many producers' technicians seemed to have more confidence in the statistical specification since the results they got were now considered record. Further confidence was gained as a result of the wider tolerances and the rela-

Table 2. Summary of average composition parameters under Addenda A.

Mixture Characteristic	Average Standard Deviation (%): 1969 Green Addenda	1970-1971 Green Addenda	1971 Yellow Addenda	Current Tolerance[a]	Average Absolute Difference in Job Mix Mean (%): 1969 Green Addenda	1971 Yellow Addenda	Standard Deviation Plus Difference[b] (%): Calculated	Rounded to Account for Test Precision	Recommended New Specification Tolerance for Five-Sample Average (%)
Mix 1									
Sieve									
No. 8	3.75	3.34	3.31	4.0	1.69	1.10	4.41	4.5	4.5
No. 50	2.01	2.08	1.93	2.5	1.26	0.47	2.40	2.5	3.0
No. 200	1.18	0.96	1.10	1.0	0.39	0.25	1.35	1.4	1.4
Average composition	0.35	0.33	0.34	0.35	0.11	0.07	0.41	0.40	0.45
Mix 2									
Sieve									
No. 8	2.91	2.90	2.77	3.00	1.91	0.92	3.69	3.5	4.0
No. 50	1.87	1.67	1.58	2.00	1.21	1.10	2.68	2.5	3.0
No. 200	0.99	0.82	0.89	1.00	0.51	0.37	1.26	1.3	1.4
Average composition	0.34	0.32	0.25	0.35	0.13	0.12	0.37	0.35	0.45
Mix 5									
Sieve									
No. 8	3.28	2.74	2.70	3.0	0.36	0.80	3.50	3.5	4.0
No. 50	2.42	2.28	1.92	2.5	0.81	0.90	2.82	3.0	3.0
No. 200	1.13	0.95	1.10	1.0	0.44	0.18	1.28	1.3	1.4
Average composition	0.30	0.26	0.26	0.30	0.11	0.17	0.43	0.45	0.45

[a] Average of five samples. [b] 1971.

tive ease of adjusting designs for normal variation in raw materials.

Process control in the average asphalt plant was not affected, however. Since most technicians were already normally sampling and testing the duplicate record sample under the "green Addenda A," the control process continued to be based on the extractions taken for record. Control at the plant may indeed have become somewhat more lax. Since the plant technician's samples were the sample of record, he could now run closer to the limits of the tolerance and not fear that the sample run in the central laboratory might be out. He could also make mix adjustments that would compensate for samples that fell outside the limit. Since there was no longer any limitation on the individual samples, he could intentionally make material out of tolerance to bring the average of five in range.

Again in 1972, the department reviewed the results of Addenda A. Afferton (2) observed that there was generally a decrease in variability since the 1969 study (Table 2). He pointed out that in spite of this one out of seven lots was still penalized. As in the earlier study, he attributed this to the producer's inability to meet his or her own job mix formula. Although some increase was observed in the producer's ability to hit the target value, Afferton generally discounted this as the result of the shift in testing laboratories. He further observed (2) that "marked changes in the producer's ability to evaluate stockpile aggregate and use statistical techniques would be needed to effect ... improvement." He felt that this would be a difficult and time-consuming process that may not be necessary since historical data suggest that the current differences in the job mix mean are comparable in magnitude to those that occurred before Addenda A when the department had complete control of plant production. As a result, a wider tolerance range was proposed for mixture composition.

Finally, in May 1973, another version of Addenda A was released. The changes represented by "blue Addenda A" were as follows:

1. Deletion of the tolerance for individual samples,
2. Inclusion of "tolerances for the range of five samples," and
3. An increase in all of the tolerances for the average of five samples.

These changes seemed to have effectively corrected the problem outlined above.

CONCLUSIONS

Because Addenda A changed so many things all at once, it is difficult to isolate the effects of the statistical process control aspect of the new specification. Ensuring that the changes in requirements for gradation and raw aggregates had a substantial effect on the asphalt mixes (whether for better or worse) would be a subject for another paper. One thing appears certain: After the application of the first penalties, nearly all producers took a keen interest in the Addenda A specification. Some were inherently skeptical and continuously sought to find defects in the specification rather than defects in the product. A few were more willing to accept the system and generally strove to control the product better. The latter seem to have fared rather well even under the earlier, more restrictive version of Addenda A.

In any event, the producer's attitude toward process control is critical to its effective application. If the producer is not convinced of the necessity or the desirability of the system, it is virtually impossible to effectively carry out a good program. No matter how competent and enthusiastic the technician may be, he can only do what the rest of the organization is geared to do.

As in any good system of process control, testing error must be kept in line with the limits allowable by the tolerance. In addition, a standardized and practical testing procedure must be published and understood by the technicians. A certain level of confidence must be established and maintained between quality control testing and acceptance testing.

It is essential, therefore, that careful consideration be given to the establishment of realistic tolerances and penalties. Since the person who pays the penalty often has little or no understanding of testing or quality control technology, that person tends to quickly judge the system in black-and-white terms. He or she generally has neither the time nor the inclination to determine why samples pass or fail. If a producer suddenly finds that he or she is being penalized often and that fellow producers are in the same position, then the credibility of the system will soon be in question. Once this occurs, it becomes very difficult for the technician ef-

fectively to keep the products under control within the system. If at the same time the technician lacks confidence in the testing and acceptance procedures, the system virtually disintegrates.

Under these circumstances, when the acceptance point is at the plant, the propensity for graft is greatly increased. When the acceptance is more distant (as in the case of cores taken from the finished product and tested in central laboratories), more involved legal battles are often encountered. In any event, the theory and practice of good statistically based quality control are completely undermined. I feel that this was the status of the Addenda A specification just before the release of the 1970 yellow Addenda A.

It is important that good delineation and coordination be established between acceptance testing and quality control testing. A good quality control program should be somewhat independent of the acceptance system. Under the existing Addenda A, acceptance testing dominates and indeed, in most cases, overpowers what I consider to be good quality control testing. In plants that have lower rates of production, there is a tendency not to do any testing until a "lot sample is due" because of the strong emphasis on acceptance samples. Indeed, if tolerances were properly established and confidence in correlation with central laboratory testing was ensured, I would rather see acceptance testing performed by the central laboratory from field samples. However, I do not wish to minimize the problem of developing such a system (especially the problem associated with a central laboratory type of operation such as that used in New Jersey in recent years). If such a system could be effectively developed, however, a more comprehensive quality control program could be used at the plant where the technician could monitor the entire operation and not just some narrow aspect of it.

Essentially, a statistically based quality control program is a vast improvement over the typical one-sample (pass or fail) system of the past. If it is to be truly effective in maintaining the quality of the product, confidence in the system must be upheld by the establishment of realistic tolerances and testing methods. It is essential that all of the involved parties thoroughly understand the theory and application of the system.

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Process Control of Mineral Aggregates

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An aggregate process control program currently used by a multiplant aggregate producer is described. The success of the program is credited to the rapid feedback of test data directly to plant management. The program uses district and plant laboratories staffed with from one to three technicians for conducting daily tests for gradation control and a central laboratory for determining other important properties of aggregates and the products in which they are used. Benefits of the program—including savings that result from minimizing rejections, improved customer relations, and other services performed by the responsible department—are emphasized. The importance of a working knowledge of basic statistical concepts by both aggregate technicians and plant management is stressed.

The process control system described in this paper is used to control the quality of aggregates at 21 plants of the Standard Slag Company. These include 11 blast furnace slag plants, 5 limestone plants, and 5 sand and gravel plants. The program is directed by the Materials Control and Research Department with a staff of 20 full-time and 5 part-time employees. Testing facilities include six district and plant laboratories, each staffed with from one to three technicians and equipped to conduct daily determinations for gradation and unit weight, and a central laboratory equipped for determining most physical and chemical properties specified for the aggregates as well as the performance of the finished products in which the aggregates are used.

Since gradation is the primary aggregate property over which the plant manager has control and since failure to comply with the specified gradation is the primary cause for rejecting aggregate from approved sources, this paper deals primarily with the control of aggregate gradation during production, handling, and recovery from stock.

The founders of our organization realized more than 50 years ago the benefits of producing quality aggregates in terms of a favorable return on investment and repeat sales. During our first encounter with statistical or end-result specifications during the late 1960s, it became apparent that increasing the effectiveness of our process control system would be a sound investment in terms of minimizing costly rejections and product liability claims and improving customer relations by supplying aggregates that have a minimal variation in specified properties. Accomplishing this meant devising a system of rapid testing and reporting that would provide immediate feedback of production control test results to plant management so that process adjustments, when necessary, could be implemented and checked for their effectiveness before a sizable quantity of nonspecification material was produced. The system now in effect was presented to the company's executive committee and received their total support.

The basic procedure used for gradation control is shown in Figure 1. Basically, each aggregate size processed in each operation is sampled in accordance with a prescribed sampling plan that stipulates sampling frequency and location and the minimum sample size. If the gradation of the sample complies with that specified, no adjustment is made. If the first sample fails to comply, a second sample is immediately selected to verify the results of the first and, at the same time, to