Bituminous Construction

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At present it is obvious that most state highway departments, as well as the Federal Highway Administration, are aware that statistically derived tolerances need be obtained. This awareness was revealed in a number of recent meetings (such as annual meetings of the Highway Research Board and the Association of Asphalt Paving Technologists, and the National Conference on Statistical Quality Control Methodology in Highway and Airfield Construction held at the University of Virginia) that included presentations on materials variability and statistically oriented specifications. It is not so evident that the highway departments are ready to use the statistically derived tolerances with end result specifications and to effect a total sampling plan, nor is it evident that contractors see the immediate need for introducing quality control procedures into their processes, mainly because the necessary incentive has not been provided.

The change to statistically oriented specifications has been and will be slow, primarily because the highway industry is reluctant to abandon the traditional methods and specifications that have been used for many years and go to new, unfamiliar techniques that are providing tolerances much larger than intuition has told us are necessary, even though the larger tolerances are demonstrably sound.

There are generally 4 steps involved in reaching a fully implemented statistical specification. The states furthest along in this program have reached the fourth step, but the majority of states have not yet begun step 1 or even made assumptions on step 1 and jumped to step 2.

The first step is the establishment of a realistic variability by either making statistical analyses of historical data or installing a separate sampling system to obtain data under a controlled procedure. The obvious advantage of the former is the saving of time, whereas the advantage of the latter is the assurance of more reliable data through the elimination of sample bias, including the discarding of some test results. Also, very few historical data have been collected by random sampling.

The variabilities have quite often been separated into testing variability, sampling variability, and materials variability. Although this separation is quite informative, particularly from a research viewpoint, it is not necessary to the establishment of realistic tolerances—as long as the same testing and sampling procedures are used in enforcing the specification as were used in collecting the data on which it was established. For instance, if tolerances are based on asphalt content data obtained from extractions by Rotorex, the same tolerances would probably not be realistic for extraction by Reflux.

There are probably about 25 highway-oriented agencies that either are still working on step 1 or have proceeded further.

The second step is the use of variability to establish realistic tolerances. Two broad options are available: either (a) merely insert the new tolerances into the conventional specifications, or (b) change the specifications entirely by adopting complete acceptance plans. For those taking the first option, this ends the immediate statistical program; but as shown later there are many other items, in addition to tolerances, that should be considered from a statistical standpoint.

The most popular currently used or proposed tolerances for bituminous concrete gradation and asphalt content may be of some interest. The tolerances, given in Table 1, are the amount the average of 5 samples may vary from the chosen job mix. Most agencies have chosen 5 as the number of samples for averaging to determine the acceptability of each lot; however, many use the average of 4, and at least one uses the average of 2 samples.

TABLE 1

TOLERANCES OF $\bar{X}_5$ FROM JOB MIX

Sieve Size	Percent Passing ±Tolerance[a]	Sieve Size	Percent Passing ± Tolerance[a]
+ 1 in.	4.5	No. 8	4.0
¾ in.	4.5	No. 30	3.5
½ in.	4.5	No. 50	2.5
⅜ in.	4.5	No. 100	1.5
No. 4	4.0	No. 200	1.0

[a]Tolerance on percent asphalt = 0.4.

There are some indications that the tolerances should be more dependent on the amount of material retained on a particular sieve rather than on the size of sieve. This would mean that 1-, ¾-, and ½-in. sieves may not need as large tolerances as they now have; however, at present the consensus is as given in Table 1. There are about a dozen agencies that have established tolerances based on either their own data or those of other agencies.

The third step is the use of the new specification in a simulation. So as not to proceed precipitously into a new and untried specification, most agencies first use a simulation process. This may be done in at least 2 ways. Most agencies first use the specification in a research-oriented project on which the contract is actually governed by the conventional specification. New York State has a different approach in that a computer is used to produce mix data that can then be tested statistically and compared to model specifications. This approach allows a great deal of flexibility and also saves much time.

The simulation affords an agency the opportunity to test the specification, particularly the number of samples and sampling procedure, under realistic conditions and to modify it if necessary. This stage generally reveals not only differences in test results, but also the need for basic philosophical decisions concerning such items as retesting and referee procedures. There are about 10 agencies that are using or have used the simulation procedure.

The fourth step is the use of the statistically oriented specification as the basis of acceptance in a contract. There are several states (Louisiana, California, Illinois, and West Virginia) that are just completing a version of a statistically defensible specification and that should soon start letting contracts under it. States that are somewhat further along in the program and are actually accepting materials under statistical specifications are South Carolina, Virginia, New Jersey, and Mississippi. In Mississippi the specification is limited to a density requirement, but the other states are concerned with asphaltic concrete production. Virginia has had a specification based on statistically derived limits for acceptance of asphaltic concrete compaction for more than 4 years, but only in the past year and a half has it accepted asphaltic concrete production based on statistical limits. South Carolina has accepted asphaltic concrete on 6 contracts and has let 12 additional contracts. Virginia has completed 5 state-financed contracts, has several more in process, and has recently received approval of the Federal Highway Administration to use its statistically based specification on federally financed projects.

TYPICAL COMPONENTS OF STATISTICAL SPECIFICATIONS

There are several components more or less inherent in all of the statistical specifications, whether they are in the simulation stage or actually in use. Some specifications include all of these items; others do not.

1. Lot Size—This is the amount of material that is to be judged acceptable or unacceptable. It is somewhat arbitrary but is generally considered to be a function of time (a day's production) or a function of production (for example, 2,000 tons). There are several considerations that must be recognized in establishing the lot size; for in-

stance, one must consider the consequences of having to reject or adjust payment, and the number of tests must be realistically compatible with the lot size.

2. Number of Samples—The number of samples that will be taken from each lot in judging acceptability must be specified. Currently, as mentioned previously, this number ranges from 2 to 5, with most states using 4 or 5.

3. Acceptance of Central Tendency—To determine the location of the mean or central tendency of the lot, the sample average is used. The average is then compared to the process tolerance around the job mix to determine acceptability. Some states, such as California, use a moving average with compatible limits to determine acceptance of this production characteristic. This measure has an integrating or smoothing effect on the test results and minimizes individual fluctuations; it is also a more continuous function than simple averages.

4. Acceptance of Variability—At present, there are at least 3 methods of limiting variability. The first method uses a limit on the amount any individual sample may vary from the central tendency. The advantage of this method is that it can be determined immediately whether or not the lot is acceptable. The disadvantage is that it is not a strong statistical technique for determining material that is actually out of specification. The second method limits the size of the standard deviation for, generally, a large amount of production. The advantage of this method is that it is more fundamental from a statistical standpoint and requires the recognition of variability. Calculation of standard deviation is a very strong incentive to improve the educational attitude of the statistically uninitiated. The third method, the use of the range to estimate variability, uses some of the advantages of both of the others and may eventually be used more widely than either of them. Typical limits used with the first two methods are given in Table 2. It should be noted that these limits are not compatible between methods. This lack of compatibility reflects the different thinking and test results that exist between agencies.

5. Other Acceptance Criteria—Some agencies have chosen to use acceptance criteria other than the ones previously mentioned. There are numerous other criteria; some being strongly considered include percent defective product, quality index (which combines acceptance of central tendency and variability into one factor), and limits based on sequential analysis.

6. Adjustment of Bid Price—Because this new form of specification is based on acceptance and leaves product control up to the contractor or producer, there is a necessity to provide for action when the product does not meet the acceptance criteria. Since for most highway products removal is impractical because of cost and difficulty, the product is used with a reduction in the bid price. If an adjustment is required, it may vary from as little as 1 percent to as great as 30 percent of the bid price. There is also some sentiment toward a positive adjustment or increase in bid price if the product is unusually uniform and close to the job mix formula. Highway administrators in several states are looking carefully at this concept.

TABLE 2

TYPICAL LIMITS USED FOR STANDARD DEVIATIONS AND INDIVIDUAL TEST RESULTS

Sieve Size	Percent Passing	
	± Individual[a]	Std. Dev.[b]
1 in.	9	4.5
¾ in.	9	4.5
½ in.	9	4.5
⅜ in.	9	4.5
No. 4	9	4.5
No. 8	8	4.0
No. 30	6	4.0
No. 50	4	3.0
No. 100	3	2.5
No. 200	2	1.5

[a]Individual limits on percent asphalt = 0.6.
[b]Standard deviation on percent asphalt = 0.3.

7. Control Charts—In an attempt to point out possible control procedures the contractor may use to control his process, control charts are being used widely. Often the data plotted on these charts are actually acceptance data, but encouragement for the contractor to make his own tests is very strong. In some cases the control charts are used to require the contractor to change his material or to shut down if the product gets out of control; but in most instances the results are merely posted so that the contractor can use them as he sees fit.

8. Retesting and Referee Procedures—As mentioned previously, the limits estab-

lished are completely dependent on the number of samples used for acceptance. This means that if a retest is necessary because the results are questionable and additional samples are necessary for clarification, the tolerances must be adjusted to agree with the sample number; and as the sample number increases, the tolerance to which the average is compared must be decreased.

SUMMARY

The use of statistically oriented end result specifications has caused some problems, and certainly they do not solve all of the engineering or materials problems, but they can solve many of the problems that indefinite and arbitrary specifications have caused in the past. The most serious problem is the lack of statistical training. The training and manpower problems that face the contractor as he assumes more control of his process cannot be dismissed easily nor can they be ignored forever. Statistical specifications are being and will continue to be increasingly used because of their clarity and defensibility. The highway industry will improve its operation if it recognizes the benefits they can provide and acts to implement the necessary procedure as quickly as possible.