Development and Implementation of Statistically Based End-Result Specifications for Hot-Mix Asphalt in Pennsylvania

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In the past, the Pennsylvania Department of Transportation (PennDOT) used the concept of single samples (the so-called "representative" samples) and tests to determine the quality of hot-mix asphalt (HMA) mixtures. This study was undertaken to develop statistically based end-result specifications for HMA pavements, which would make the contractor responsible for quality control and would make PennDOT responsible for quality assurance. Field data from several HMA paving projects were analyzed statistically to establish realistic numerical limits for the various test parameters to be used in the specifications. The type of samples (loose mixture behind the paver screed or core specimens) to determine the mix composition (asphalt content and gradation) of the end product was also established. The proposed specifications require loose-mix samples behind the paver to determine the mix composition, and core samples are required to determine the compacted mat density. All acceptance testing is done by PennDOT. Three pay items (asphalt content, the percent passing 75μm or No. 200 sieve, and mat density) were included in the specifications. Realistic numerical tolerance limits for these test parameters were based on the statistical analyses of the field data and ASTM precision statements. A weighted-price adjustment formula (which gives 50 percent weight to mat density and 25 percent each to asphalt content and minus 75μm material) was incorporated in the specifications. The implementation of these specifications has improved the overall quality of HMA pavement in Pennsylvania. The specifications have provided PennDOT with a means of evaluating and comparing the dollar value of the improvement in HMA quality year-by-year.

The Pennsylvania Department of Transportation (PennDOT) had for years used extraction, density, and Marshall tests for the quality control of hot-mix asphalt (HMA) construction. Associated with these procedures was the concept of single samples (the so-called "representative samples") and tests to indicate the quality of HMA mixtures. If the results were not within some arbitrary limits, it was common for researchers to obtain additional samples—sometimes called investigation, confirmation, check, or referee samples—to decide whether to accept or reject the material.

By using the old HMA specifications, PennDOT had placed itself in the undesirable position of assuming the responsibility for both quality control and acceptance of the material or construction. It was decided that the contractor should be responsible for quality control of the product and that PennDOT should be responsible for defining the acceptance standards for the product and ensuring compliance with these standards. Therefore, it was important to develop and implement statistically based end-result specifications for HMA. The advantages of such specifications are as follows:

1. The required quality may be stated more clearly by including reasonable variation tolerances.
2. When ground rules for acceptance, rejection, and adjusted compensation are clearly stated in the specifications, the time and expense involved in negotiations and settlements of claims will be minimized.
3. The concepts of random sampling and formulated acceptance plans will minimize the risk of making wrong decisions.
4. The judgment factor, which has constantly plagued the engineer, will be minimized. Consequently, the engineer's decisions will be legally defensible.

The main objective of this study was to develop such specifications based on the statistical analysis of field data from HMA paving projects in Pennsylvania. The intent was not to develop performance-based specifications, although they would be a desirable result. It was necessary to determine whether core samples or loose-mix samples behind the paver screed should be used for determining the acceptance of HMA composition (asphalt content and gradation).

FIELD DATA

It was necessary to gather and statistically analyze field data from several HMA paving projects to establish realistic numerical limits for the statistically based end-result specifications. This work was done in three phases.

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Phase 1

This phase was conducted from 1968 through 1972 and involved statistical analysis of data from two sources: (a) historical data consisting of about 4,600 measurements of random samplings of HMA mixtures at the job site during 1968 and 1969 and (b) data obtained from a series of statistically designed experiments during 1969 and 1970 involving about 6,600 unbiased measurements of normal HMA materials and routine construction. Measurements investigated included asphalt content, gradation, Marshall properties, and pavement density of dense graded wearing and binder mixtures. The detailed data are presented elsewhere (*1*).

Tables 1 and 2 present the standard deviations for wearing and binder mixtures, respectively, for the projects constructed in 1970. The standard deviations for the asphalt content, 75 μm (No. 200) material, Marshall stability, and air voids for the wearing and binder course mixtures compare favorably with the following national standard deviation averages published in 1966 (*2*) by the Office of Research and Development, Bureau of Public Roads (now FHWA).

	Asphalt Content	*75 μm (No. 200)*	*Stability*	*Air Voids*
Wearing course	0.27	0.88	246	0.77
Binder course	0.33	0.93	258	0.74

TABLE 1 Standard Deviations for Wearing Course Mixtures (*1*)

Characteristic	Project					
	70-A1	70-C1	70-E1	70-E	70-4	Pooled
3/8 inch	0.9	0.9	2.0	1.6	1.6	1.56
No. 4	3.8	2.1	3.1	2.9	3.6	3.19
No. 8	3.3	1.5	2.2	2.3	2.7	2.47
No. 16	2.9	1.9	2.1	2.0	2.0	2.15
No. 30	2.3	2.4	2.2	1.9	1.2	1.93
No. 50	1.0	2.1	2.0	1.8	0.9	1.58
No. 100	1.0	1.6	1.3	1.5	0.6	1.18
No. 200	0.2	1.1	0.8	1.2	0.5	0.80
Asphalt Content	0.10	0.13	0.21	0.24	0.32	0.20
Stability, lbs.	290	251	281	247	275	269
Flow, unit	1.54	1.41	1.65	1.38	1.79	1.55
Bulk Specific Gravity	0.0287	0.0289	0.0271	0.0260	0.0281	0.0278
Air Voids	1.17	0.85	0.85	0.71	0.92	0.90
VFA	5.95	3.26	3.89	4.11	4.01	4.24
VMA	1.09	1.25	1.13	1.31	1.05	1.17

TABLE 2 Standard Deviations for Binder Course Mixtures (*1*)

Characteristic	Project					
	70-A2	70-C2	70-D2	70-1	70-2	Pooled
1 inch	2.2	2.2	3.5	3.1	1.9	2.58
1/2 inch	4.0	3.9	6.2	6.4	5.2	5.18
No. 4	3.0	2.5	3.4	4.4	3.6	3.47
No. 8	2.7	2.1	2.0	2.8	2.2	2.27
No. 16	2.3	1.3	1.4	1.5	1.4	1.62
No. 30	1.7	0.9	1.2	1.0	0.9	1.16
No. 50	1.1	0.8	1.0	0.7	0.9	0.89
No. 100	0.2	0.7	0.5	0.6	0.8	0.60
No. 200	0.6	0.8	0.5	0.5	0.7	0.62
Asphalt content	0.20	0.20	0.20	0.29	0.33	0.24
Stability, lbs.	309	303	315	299	307	307
Flow, unit	4.66	4.12	4.31	4.09	4.55	4.35
Bulk Specific Gravity	0.0241	0.0172	0.0255	0.0185	0.0196	0.0210
Air Voids	0.85	0.65	0.79	0.83	0.71	0.77
VFA	4.05	3.27	3.39	4.13	4.02	3.77
VMA	1.09	1.04	1.04	1.07	1.08	1.06

Phase 2

It appeared necessary to use the mix composition (asphalt content and gradation) and the mat density (compaction) as the acceptance criteria in the proposed specifications. Pavement cores have to be obtained after the compaction of the mat to determine pavement density, and the question of whether these density cores may also be used to ascertain the mix composition arose. This would eliminate the need to take additional loose-mix samples behind the paver screed for mix composition and thus minimize the number of samples per lot. The feasibility of this idea was examined in Phase 2 in 1979.

Several paving projects were selected across Pennsylvania that would provide core versus loose-mix composition data for both wearing and binder courses. Different aggregate types—gravel, sandstone, and slag—were used in the HMA mixtures sampled from these paving projects. The loose samples were taken directly behind the paver screed by means of a flat-bottom, high-sided scoop. Pavement cores 152.4 mm (6 in.) in diameter were drilled with a power-driven, water-cooled drill.

Statistical data summaries were prepared for both loose sample and core extraction results. The conformal index (CI) was used to evaluate target miss (deviation) of HMA mixtures in relation to job-mix formulas (JMFs). This procedure affords the opportunity to evaluate HMA mixtures of different JMFs. CI, like the standard deviation, is a measure of dispersion. However, the standard deviation (σ) is the root mean square of differences from the average, or central value, whereas CI is the root mean square of the differences from a target (JMF), or specified value. In other words, the standard deviation is a measure of precision, whereas CI is a measure of exactness or degree of accordance with a standard (*1*). The following equations are used to calculate the standard deviation (σ) and CI:

$$\sigma = \sqrt{\frac{\Sigma (X - \overline{X})^2}{(n - 1)}}$$

$$CI = \sqrt{\frac{\Sigma (X - T)^2}{n}}$$

where T is a target value, such as JMF asphalt content.

CI values were calculated for asphalt content, material passing 2.36 mm (No. 8) sieve, and material passing 75 μm (No. 200) sieve for both wearing and binder mixtures used on each project. CI values were also calculated for the material passing 12.7 mm (1/2 in.) sieve in case of binder mixtures. Table 3 presents the average CI value ($\overline{X}$) and the standard deviation (σ) of the CI values for all wearing course projects. The data have been broken down for gravel and sandstone aggregates. Table 4 presents similar data for all binder course projects. Although the data are rather limited, some generalizations can be drawn. The CI values for the aggregate gradations associated with the core samples are generally greater than those shown by the loose sample aggregate gradations. Consequently, it appears that there is substantial degradation associated with the core sampling. Degradation of the aggregate may occur during compaction of the mat and subsequent coring and sawing operations. The extent of degradation appears to be dependent on the aggregate and mix types. It is apparent that the aggregate degradation is more pronounced with the sandstone aggregate as compared with the gravel aggregate, and with the binder course mixtures as compared with the wearing course mixtures. According to the Student's *t*-test analysis, the differences in CI values (of 2.36 mm and 75 μm materials) between core and loose samples were generally statistically significant at the 5 percent level (*3*). Therefore, it was established that core samples cannot be used for mix composition acceptance, and loose-mixture samples have to be obtained behind the paver screed.

Phase 3

Six HMA paving projects were selected in 1980 to evaluate the specification tolerances obtained in Phase 1. Loose-mix samples were obtained behind the paver screed lot by lot. Lots were 5,601 m² (6,700 yd²) or 1,525 m (5,000 linear ft). Each lot was stratified into five equal sublots. A loose sample was obtained at random in each sublot and extracted to determine the mix composition.

The mix composition data (asphalt content, material passing 2.36 mm sieve, and material passing 75 μm sieve) from these six projects, which consisted of wearing course only, were analyzed statistically. Table 5 presents a comparison of specification tolerance limits (derived from the sample standard deviation values) obtained in Phases 1 and 3 with the existing PennDOT limits based on one sample ($n = 1$). The standard deviation values given in the table include variations resulting from sampling, testing, and material type. The standard deviation values for Phase 1 are based on the data obtained in 1969 and 1970, unlike Table 1, which is based on data from 1970 only.

TABLE 3 Mean and Standard Deviation of CIs for Core and Loose Samples (Wearing Courses)

Aggregate Type	Core Samples						Loose Samples					
	Percent AC		Percent Passing 2.36 mm Sieve		Percent Passing 75 μm Sieve		Percent AC		Percent Passing 2.36 mm Sieve		Percent Passing 75 μm Sieve	
	$\overline{x}$	σ	$\overline{x}$	σ	$\overline{x}$	σ	$\overline{x}$	σ	$\overline{x}$	σ	$\overline{x}$	σ
Gravel	-0.33	0.20	0.95	2.24	1.40	1.37	-0.36	0.13	0.13	2.58	0.48	1.27
Sandstone	-0.07	0.14	3.02	2.09	1.40	0.90	-0.004	0.20	-0.27	2.59	0.77	1.31

TABLE 4 Mean and Standard Deviation of CIs for Core and Loose Samples (Binder Courses)

Aggregate Type	Core Samples								Loose Samples							
	Percent AC		Percent Passing 12.7 mm Sieve		Percent Passing 2.36 mm Sieve		Percent Passing 75 μm Sieve		Percent AC		Percent Passing 12.7 mm Sieve		Percent Passing 2.36 mm Sieve		Percent Passing 75 μm Sieve	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Gravel	-0.05	0.23	5.39	4.35	2.46	1.79	2.16	0.94	-0.30	0.17	1.00	2.00	-0.67	1.16	1.37	0.58
Sandstone	0.12	0.26	7.50	2.81	0.50	1.38	2.50	0.84	-0.13	0.06	-3.67	3.79	-3.33	0.58	2.00	0.00

Based on normal distribution theory, the total dispersion expected from individual measurements is $\pm 3\sigma$ units, and for multiple sample or sample means, it is $\pm 3\sigma_{\bar{X}}$.

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}}$$

where σ is the standard deviation of individual measurements and n is the sample size. The symbol $\sigma_{\bar{X}}$ is commonly referred to as the standard error of the mean.

It would appear from Table 5 that the existing PennDOT specification limits are too restrictive for single or individual (n = 1) samples. The existing specification limits are more in agreement for a sample size of 5. The standard deviation values and resultant specification limits also indicate that the existing PennDOT specification limits are too tight for individual samples.

The same technicians performed the experimental work throughout Phase 1. However, different technicians performed the sampling in Phase 3, which resulted in somewhat higher standard deviation values than those obtained in Phase 1.

Cores were also obtained from these six projects to measure the mat density. The minimum specification limit for compaction was 92 percent of theoretical maximum specific gravity. The contract governing the six projects stated that for 100 percent payment the lot average for compaction ($\bar{X}$) must be 92 percent or greater, with no individual sublot value below 90 percent of theoretical maximum specific gravity. The average compaction ($\bar{X}$) for all six projects was computed to be 92.8 percent, with a standard deviation (σ) of 0.87 percent. On the basis of these data it appears that the specification limits were proper and realistic:

$$\bar{X} - 3\sigma = \text{lower specification limit}$$

$$92.8 - 3(0.87) = 90.2$$

DEVELOPMENT OF SPECIFICATIONS

A department-industry task force was organized by PennDOT to review the statistical analysis of the extensive test data obtained in Phases 1, 2, and 3, and develop statistically based end-result specifications. These specifications were to be established on the basis of acceptable existing construction quality levels. The contractor would submit a quality control plan (with no minimum numbers of tests mandated by PennDOT) to PennDOT and would be entirely responsible for quality control. PennDOT would obtain acceptance samples (loose-mix samples behind the paver for mix composition and core samples for compaction testing) at random on a lot-by-lot basis. These samples would be tested in the PennDOT Central Laboratory, where the lot statistics [such as percent within limits (PWL)] and the pay factors would also be computed.

On the basis of the experience from 6 pilot projects in 1980 and 16 pilot projects in 1981 (*3*), the following observations were made and conclusions were reached:

1. The statistical acceptance criteria should be based on three items only: asphalt content, percent passing 75 μm (No. 200) sieve, and percent compaction in the mat based on theoretical maximum specific gravity. It was believed that the percent passing 2.36 mm (No. 8) sieve need not be a pay item because this characteristic would be reflected indirectly by the percentage compaction. However, contractors must maintain quality control charts showing day-to-day fluctuations in the materials passing all specified sieves. When adverse trends are noted or the material is consistently outside the JMF gradation limits or other Marshall test parameters (such as stability, flow, air voids, and voids in the mineral aggregate), the HMA facility may be shut down.

2. The multiple deficiency formula, when applied to the 1980 pilot projects, resulted in severe price adjustments. For example, if the asphalt content for a given lot was calculated to be paid at 100 percent of the contract unit price, the minus

TABLE 5 Comparison of Proposed Specification Limits from Phases 1 and 3 with Existing PennDOT Limits (Wearing Course)

Mix Property	Phase 1			Phase 3			Existing PennDOT Spec. Limits (n=1)
	Sample Standard Deviation σ	Proposed Spec. Limits 3σ (n=1)	Proposed Spec. Limits $3\sigma_{\bar{x}}$ (n=5)	Sample Standard Deviation σ	Proposed Spec. Limits 3σ (n=1)	Proposed Spec. Limits $3\sigma_{\bar{x}}$ (n=5)	
Asphalt Content	0.22	±0.66	±0.30	0.25	±0.75	±0.34	±0.4
2.36 mm (No. 8) Sieve	2.58	±7.74	±3.46	3.35	±10.05	±4.49	±4
75 μm (No. 200) Sieve	0.78	±2.34	±1.05	0.98	±2.94	±1.31	±2

75 μm (No. 200) material to be paid at 90 percent of the contract unit price, and the compaction to be paid at 85 percent of the contract unit price, the resultant payment would be the product of the three percentages:

100 percent × 90 percent × 85 percent = 76.5 percent

The value 76.5 percent is more severe than the individual percentages used to make the calculations.

Approximately 23 percent of the total bid price for the six projects in 1980 sustained a price adjustment. It has been reported that equitable price adjustments associated with statistical acceptance plans should be expected between 5 and 10 percent (*4*).

It was decided to use a weighted price adjustment approach, which would be based on the criticality of the three characteristics evaluated (asphalt content, minus 75 μm material, or mat density) on the performance of the HMA pavement. Most asphalt paving technologists would agree that of the three characteristics, the mat density is by far the most important to avoid premature failure and to ensure reasonable serviceability and performance of an HMA pavement. Therefore, 50 percent payment was made attributable to mat density (or compaction), 25 percent payment to asphalt content, and 25 percent payment to minus 75 μm (No. 200) material.

3. The specification tolerances developed in Phases 1 and 3, the experience from the pilot projects in 1980 and 1981, and ASTM's precision statement for the extraction testing procedure (ASTM D2172) were considered to develop specification tolerances for asphalt content and minus 75 μm (No. 200) material (Table 6). According to ASTM, the results of two properly conducted tests from two different laboratories, on samples from the same batch, should not differ by more than ±0.81 for asphalt content. This is reflected in the proposed specification tolerances (Table 6) for a single sample ($n = 1$).

4. A screening process must be incorporated in the specifications to provide an incentive for the contractor to target the JMF. This process must be simple and easily understood by contractors who are not well versed in statistics. Therefore, a bonus-penalty point approach should be placed in the specifications to reward or penalize the contractor depending on the precision with which the JMF was reproduced. Sampling, testing, and materials variations should be taken into account. The same approach should be applied to the density acceptance criteria.

The following sections summarize the acceptance criteria and basis of payment included in the statistically based end-result specifications.

Mix Characteristic Acceptance

After the JMF is approved, the contractor shall test for asphalt content and aggregate gradation in accordance with the submitted quality control plan. The mixture shall be controlled for individual test samples ($n = 1$) within ±0.7 percentage points of the JMF for asphalt content in the wearing course, ±0.8 percentage points of the JMF for asphalt content in the binder course, and ±3.0 percentage points of the JMF for the 75 μm (No. 200) sieve for both wearing and binder courses.

The mixture shall be controlled for the lot average ($\overline{X}$) of multiple test samples ($n = 5$) within ±0.4 percentage points of the JMF for asphalt content in the wearing course, ±0.5 percentage points of the JMF for asphalt content in the binder course, and ±2.0 percentage points of the JMF for the 75 μm (No. 200) sieve for binder and wearing course materials.

The lot shall be accepted with respect to asphalt content and percent aggregate passing the 75 μm (No. 200) sieve under the following three conditions.

Condition 1

The lot will be accepted at 100 percent payment factor for percent asphalt content when no individual test result for the lot, based on the JMF, deviates from the requirements for binder or wearing (Table 6), and the lot average ($\overline{X}$) of all tests within the lot falls within ±0.2 percentage points of the JMF for wearing course material and ±0.3 percentage points of the JMF for binder course material. One bonus point shall be assigned for the lot.

The lot will be accepted at 100 percent payment factor for percent aggregate passing the 75 μm (No. 200) sieve when no individual test result based on the JMF deviates from requirements for binder or wearing course (Table 6) and the lot average ($\overline{X}$) of all tests within the lot falls within ±1.0 percentage points of the JMF. One bonus point shall be assigned for the lot.

Condition 2

Whenever the lot average ($\overline{X}$) for asphalt content (wearing) falls between ±0.2 and ±0.4 percentage points of the JMF and no individual test result deviates more than ±0.7 percentage points from the JMF, one penalty point will be assigned for the lot.

Whenever the lot average ($\overline{X}$) for asphalt content (binder) falls between ±0.3 and ±0.5 percentage points of the JMF

TABLE 6 Specification Tolerances for Asphalt Content and Minus 75 μm Material from JMF

Mix Characteristic	Individual Sample (n = 1)		Sample Average (n = 5)	
	Binder	Wearing	Binder	Wearing
Asphalt Content (%)	± 0.8	± 0.7	± 0.5	± 0.4
75 μm Sieve (% Passing)	± 3.0	± 3.0	± 2.0	± 2.0

and no individual test result deviates more than ±0.8 percentage points from the JMF, one penalty point will be assigned for the lot.

Whenever the lot average ($\overline{X}$) for percent aggregate passing the 75 μm (No. 200) sieve falls between ±1.0 and ±2.0 percentage points of the JMF and no individual test result deviates more than ±3.0 percentage points from the JMF, one penalty point will be assigned for the lot.

Condition 3

Whenever an individual test result or the lot average ($\overline{X}$) for the percent asphalt content or percent aggregate passing the 75 μm (No. 200) sieve deviate from the tolerances (Table 6), the percent within tolerance or limits for that characteristic(s) and the payment factor percentage will be determined (*5*). Lot payment will be determined in accordance with the weighted price adjustment formula.

Density Acceptance

For the binder and wearing course, the lot will be accepted with respect to compaction for one of the following conditions.

Condition 1

The lot shall be accepted at 100 percent payment factor for density if the lot average ($\overline{X}$) of the density results is 92 percent of theoretical maximum density or greater and no sublot test is below 90 percent of theoretical maximum density. Two bonus points shall be assigned for the lot.

Condition 2

Whenever the lot average ($\overline{X}$) of the density results falls between 90 percent and 92 percent of theoretical maximum density and no sublot test falls below 90 percent of theoretical maximum density, two penalty points will be assigned for the lot.

Condition 3

If one or more sublot tests fall below 90 percent of theoretical maximum density, a quality index value, Q_L, will be computed for the lot from the following formula:

$$Q_L = \frac{\overline{X}n - 0.90\,T}{s}$$

where

n = number of density measurements on the lot,
$\overline{X}$ = average of n density measurements (lb/ft^3),
T = theoretical maximum density (lb/ft^3),
s = standard deviation, and
Q_L = quality index value.

The PWL for the lot will be determined for the previously determined quality index value (Q_L). The payment factor percentage will then be determined from PWL. Lot payment will be determined in accordance with the weighted price adjustment formula.

Basis of Payment

The ID-2 binder and wearing courses will be paid for at the contract unit price per square yard or contract unit price per ton as follows:

1. If the percent aggregate passing the 75 μm (No. 200) sieve, the percent asphalt content, and percent compaction all fall within Condition 1, the contract unit price per lot will be paid at 100 percent.
2. If the percent aggregate passing the 75 μm (No. 200) sieve, percent asphalt content or percent compaction fall within Condition 2, the bonus (positive values) and penalty points (negative values) will be accumulated algebraically for the lot. One bonus point will cancel one penalty point. A lot indicating a negative cumulative total for the bonus and penalty points will be paid at 98 percent of the contract unit price. A lot indicating zero or a positive total will be paid at 100 percent of the contract unit price.
3. If one or more of the acceptance characteristics do not fall under items 1 or 2, the adjusted percentage of contract price to be paid per lot will be computed as follows:

$$Lp = Cp\,\frac{(2P_D + P_M)}{400}$$

where

Lp = lot payment,
Cp = contract unit price per lot (unit price times lot quantity),
P_D = payment factor percentage for density, and
P_M = payment factor percentage (sum) for percent asphalt content and percent aggregate passing 75 μm (No. 200) sieve.

For those characteristics meeting items 1 or 2, the applicable payment factor will be entered into the formula for calculation purposes.

The engineer reserves the right to remove and replace the lot when any one of the three acceptance parameters (percent asphalt content, percent 75 μm material, percent compaction) falls below 64 PWL. In lieu thereof, the contractor and the engineer, after review, may agree in writing that, for practical purposes, the deficient lot should not be removed and should be paid for at 50 percent of the contract unit price.

IMPLEMENTATION OF SPECIFICATIONS

These statistically based end-result specifications developed through the joint effort of PennDOT and the HMA industry were implemented in 1982.

Training

An extensive training program was undertaken in 1981 to train PennDOT and industry personnel in basic statistics and all aspects of this specification, such as random sampling, lots and sublots, PWL, and pay factors. This training program was continued for several years.

Testing

These end-result specifications require acceptance testing by PennDOT; some other states use contractors' test data. Since the lot size is approximately equal to one lane 1.61 km (1 mi) long, five loose-mix samples and five core samples are obtained and tested by PennDOT for each lane mile of HMA paving. This is a large task of testing undertaken by PennDOT's central laboratory. In 1 of the past 10 years, about 1,600 lane mi were paved by PennDOT under these specifications, which required performing about 8,000 extraction tests (on loose samples behind the paver) and about 8,000 density tests (on pavement cores) by the central laboratory. However, the asphalt laboratory crew has consistently delivered quality test results during the past 10 years.

The extraction laboratory staff consists of one materials supervisor and four materials technicians. The laboratory has 24 extractors. Each technician is responsible for six extractors. During a regular work day (7.5 hr), 48 extraction tests (12 per technician) are performed. On a day with overtime (12.5 hr), the output is doubled, and 96 tests can be performed.

The density laboratory staff consists of one materials supervisor and two materials technicians. During a regular work day, density tests are performed on 75 cores. When overtime is used, the output is doubled, and 150 cores can be tested.

The testing quality of the laboratory personnel is checked frequently by introducing referee samples (of known mix composition or density) in the testing system without the knowledge of the testing technicians.

The asphalt laboratory testing staff of only eight people has been able to cope with testing of all acceptance samples from the entire state. This has enabled PennDOT to reduce the number of HMA plant inspectors significantly because the end product behind the paver screed is tested for acceptance. PennDOT's district personnel are satisfied with these specifications because the judgment factor in evaluating the quality of the end product and deciding the price adjustments has been practically eliminated. The districts and contractors now get a lot-by-lot printout of extraction and density test results, PWL, and the pay factor. Although the test results are not available to contractors to make timely adjustments or corrections in the HMA paving operations, contractors may perform their own tests (with no minimum number of tests mandated by PennDOT) to maintain quality control.

Retests

When a lot involves price adjustments, all sublot samples (loose mix or cores) in that lot are saved by the central laboratory because the contractor may request a retest of that lot. If requested, retesting of all sublot samples (although only one or two of the five sublot samples may be outside tolerance limits) is done in the presence of the contractor's representative. Both the original test values and the retest values are analyzed statistically to determine if they are significantly different at the 5 percent level. Pennsylvania Test Method No. 5, which is used to compare the means and standard deviation of the two sets, is used for this statistical analysis. This process eliminates the judgment factor. If the retest values indicate repeatability, the original test values are used, and the cost of the additional testing for the lot (10 times the unit bid price per ton of HMA) incurred by PennDOT is borne by the contractor. However, if the retest values indicate a lack of repeatability, the retest values are used, and the cost of the additional testing is borne by PennDOT.

Results

Both PennDOT and HMA industry personnel have adapted to the statistically based end-result specifications during the past 10 years. These specifications have practically eliminated premature distress and have increased the serviceability and durability of HMA pavements in Pennsylvania by improving the quality of the end product on the roadway. This paper was prepared belatedly to include these long-term observations.

The specifications have provided PennDOT with a means of evaluating and comparing the dollar value of the improvement of HMA quality year-by-year. Overall, the percentage of lots subjected to price adjustments has ranged from 4 to 6 percent during the last 4 years. During 1991, 5 percent of the total lots tested had price adjustments. Of these lots, 73 percent were deficient in mat density, 12 percent were outside the tolerance for minus 75 μm (No. 200), 6 percent were deficient in asphalt content, and 3 percent were excessive in asphalt content.

PennDOT now allows computer printed tickets from an automated HMA facility in lieu of loose-mix samples behind the paver. Reduced tolerances are used for asphalt content in such cases. However, verification samples are obtained for each 454 Mg (500 tons) and tested by the central laboratory.

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