The use of Percent Defective (PD) specifications started with the military in the 1950s, and its complement, Percent Within Limits (PWL), was proposed for use in the highway field in the 1970s. Although the PD and PWL specifications are exactly the same concept, PWL is used because it has a psychologically more positive connotation.

Guidance on the establishment of PWL specifications may be found in the AASHTO Standard Recommended Practice R9. All parties considering PWL specifications should read this document, discuss it, and follow it.

The PWL for any given pavement characteristic will be defined by how the limits are set. If the characteristic needs to be above some minimum, then only a lower limit is used. If a range is specified, then upper and lower limits are fixed. The concept of PWL is illustrated in Figure 1, where the curve generated from the test results shows the probability that 20% of the material falls outside the specified range. In this case, 80% of the material would be within limits.

Conceivably, all test values from samples taken within a lot could fall within the limits of the specified range, but because of the mean and standard deviation of the test results, a certain percentage of the material is considered to fall outside the range. When this happens, AASHTO R9 suggests an investigation and reevaluation of the test results before applying any resulting penalties.

The AASHTO procedure acknowledges the need to account for sampling and testing variability within the specification. It also states the need to keep the specification clear and unambiguous as well as the need to set acceptable quality levels at realistic values. It does not, however, discuss the development of pay factors or the use of interrelated test results in the preparation of specifications.

The use of pay factors normally begins when the PWL falls below a certain level. Once the PWL becomes
Therefore, the greater the degree of interrelationship between variables used for pay factors, the greater the likelihood the product will not fall within the combined acceptable limits and the more likely it is that penalties or disincentives will result.

**Statistical Comparisons**

It is sometimes useful to compare either data from two samples or data from a sample against that of a population. This is usually accomplished by comparing the means and the variances.

A comparison of means from two samples may be accomplished by using a t-test, in which the hypothesis that the two means are equal is either accepted or rejected at some level of certainty. In this manner, it is possible to determine whether or not the samples represent the same population. This type of test may be employed during the verification of a mix design or in comparing results on a split sample of material.

It may also be useful to compare the variances of two sample sets to see if the variances are equal. Again, a specific type of statistical test called an F-test is employed to judge whether the hypothesis of equal variances can be accepted or rejected. This type of statistical test can be used in setting reasonable limits for within- and between-laboratory testing variability.

**Issues in Statistical Specifications**

A lot is normally the amount of production on which decisions for payment are made. The sizes of lots and sublots need to be reasonably set. A lot needs to represent a quantity of material manufactured under uniform conditions, yet it should be large enough to minimize the amount of paperwork necessary for payment. Sublots are equal divisions of a lot from which random samples are taken to represent a lot. Sublots are used to avoid the possibility that random samples of material are taken within close proximity of each other and would not necessarily be representative of the whole lot. Usually lots of material are divided into four or five sublots.

The number of samples in a lot needs to be sufficient to statistically describe the material without overwhelming the laboratory capability to produce quality test results and provide timely turn-around for feedback and decision-making. Sometimes, to ensure the statistical validity of the normal distribution, results from two or more samples within a sublot are averaged and the sublot averages are then used as individual samples in the student distribution analysis.

The precision and bias of test methods needs to be established at state and regional levels. Such information exists at the national level in ASTM and AASHTO test methods. Performing “round robin” testing at a more local level will ensure proper consideration of test method variability within the specification limits.
The establishment of specification limits needs to be done with an understanding of the value added for increasingly higher quality levels versus the amount of diminishing returns for more restrictive limits. The specification limits must be set with a thorough understanding of the risks to be taken by the agency and the contractor. Any Percent Within Limit specification should be written using the guidance in AASHTO R9, and it should be written such that interdependent variables are properly accounted for in establishing limits and buyer’s and seller’s risks.

The establishment of a Job Mix Formula is often subject to the agency’s verification of the contractor’s mix design. In considering the limits needed to accept the contractor’s mix design, it is necessary to incorporate the expected variability due to sampling and testing. Thus, for a split sample of material, the expected variability might be defined by the precision and bias statements in ASTM testing methods. However, it is more desirable to establish this for the local practice through round robin testing.

Whenever possible, trial sections should be constructed and tested prior to full production. Such sections may be used to discover problems with materials and construction that can be resolved early. Test results from these sections may also be used to evaluate the reasonableness of specifications and provide time to adjust limits.

Desirable Features of Statistical Specifications

The following list of attributes should pertain to any sound statistical specification and it should be used in establishing discussion points with agencies considering changes to their specifications.

1. The specifications must be written in a form that is understandable and biddable.
2. The agency’s expectations for the characteristics of the product must be clearly stated.
3. The agency’s and contractor’s risks must be clearly defined, preferably using operating characteristic curves.
4. The points of sampling, frequency of sampling, and the methods of testing must be clear and unambiguous.
5. The specified quality characteristics should be preferably tied to the performance of the HMA. If this is not done quantitatively, then it should be done at least qualitatively, with agreement between the agency and contractors.
6. The level and variability of the quality characteristics should be established on the basis of good historical test records from accredited laboratories and certified technicians.
7. The variability of test methods (precision and bias) should be acknowledged and accounted for within the allowable variability in the quality characteristics. These should be established on a state level for the most accurate assessment of the impact of test method variability on the final result.
8. When interdependent variables are used as quality characteristics for pay items, concepts of conditional probability must be used to appropriately define risks for the agency and contractor.
9. All assumptions inherent in the statistical analysis of the test results and the subsequent actions must be clearly stated.
10. The contractor should be given as much room for innovation as possible to meet the goal of the specifications.
11. Quality assurance test results and subsequent decisions on payment should be made as soon as possible, preferably within 24 hours.

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