Statistical Specifications For Hot Mix Asphalt:

What Do We Need to Know?

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Editor's Note: This article is the first in a three-part series discussing the background, current state, and future of statistical specifications for Hot Mix Asphalt. The advantages and weaknesses of statistical approaches to material specifications are presented along with an explanation of desirable features for specifications. This article presents a historical background of specifications and an explanation of statistical concepts. The next article will discuss Percent Within Limits specifications, issues in statistical approaches, and desirable features for specifications. The last article will discuss the future with respect to Performance Related Specifications.

Introduction

Specifications are used to convey information concerning desired products from a buyer to a seller or potential seller, they are used as a basis for competitive bidding for the delivery of products and they are used to measure compliance to contracts. There are four types of specifications generally recognized in the construction industry: 1) proprietary product, 2) method, 3) end-result, and 4) performance.

A proprietary product specification is used when a generic description of a desired product or process cannot be easily formulated. It usually contains an “or equivalent” clause to allow for some measure of competition in providing the product. It is generally acknowledged that such a specification severely limits competition which increases cost. It provides very little latitude for innovation, and it puts substantial risk on the owner for product performance.

Most agencies avoid this type of specification whenever possible.

A method specification outlines a specific materials selection and construction operation process to be followed in providing a product. In the past, many construction specifications were written in this manner. A contractor would be told what type of material to produce, what equipment to use, and in what manner it was to be used in building a structure. In its strictest
sense, only the final form of the structure can be stipulated (for instance, the thickness of the pavement layers). This type of specification allows for a greater degree of competition than the proprietary product specification, but as long as the structure is built according to the materials and methods stipulated, the agency bears the responsibility for the performance. Contractor innovation is severely restricted in this environment.

An end-result specification is one in which the final characteristics of the product are stipulated, and the contractor is given considerable freedom in achieving those characteristics. In their roughest form, they specify minimum, maximum, or a range of values for any given characteristic. For instance, they may state a minimum layer thickness or a range of in-place air voids. Normally, agencies try to use statistical techniques in employing end-result specifications. In well-written specifications, the statistics account for sources of variability (sampling and testing) when placing limits on the material variability. Despite the term “end-result,” some elements of method specifications are usually incorporated to guard against early failure of the product. This is the current general state of highway specifications. In the future, efforts will be made to tie the end-result quality characteristics for the product to its performance; these will be referred to as performance-related specifications. Performance-based specifications will rely on characteristics or properties directly related to the expected performance.

Performance specifications are those in which the product payment is directly dependent upon its actual performance. Typical of these specifications are warranty, limited warranty and design-build-operate contracts. Contractors are held responsible for the product performance within the context of what they have control over. The contractor is given a great deal of leeway in providing the product, as long as it performs according to established guidelines. In this case, the contractor assumes considerable risk for the level of service the product provides by paying for or providing any necessary maintenance or repair within the warranty period.

The use of statistics in specifications is appropriate when considering the variability inherent in any product and the variability associated with sampling and testing activities. When properly formulated, the statistical description of desired characteristics provides the best insurance that the buyer is getting what was paid for and that the seller will be paid a fair price for delivering the product. Depending upon the importance of a characteristic to define the performance of the product, a trade-off will need to be made between the quality of the product (limiting variability) and its associated cost.

The AASHO Road Test completed in the early 1960s illustrated the importance of statistics in defining pavement features. It was found that the Road Test materials, as tested, did not conform to specifications at all times. The lack of compliance to the specifications was not related to the materials’ inability to perform adequately. This revelation also led agencies to consider what was achievable in terms of sampling and testing. Out of this was born the concept of quality control/quality assurance (QC/QA) specifications for the highway industry.

Many agencies have adopted QC/QA specifications for Hot Mix Asphalt, and others are in the process of developing them. Contractors and agency personnel need to be aware of the basis for statistical specifications, the terminology associated with them, and the potential pitfalls of incorrectly formulated or modified specifications.

**Statistics**

Statistics is an area of mathematics used for describing the characteristics of data such as its central tendencies and dispersion. The appropriate starting point for understanding statistical specifications is in the elementary concepts. An understanding of these will help in establishing a dialog with specifying agencies. Sampling is one of the most important features in QC/QA specifications. In particular, one needs to know where to sample (point of sampling), how to sample (what technique to use), how much to sample (quantity or number of samples), and when to sample (by time or production rate). If sampling is done inappropriately, a bias in test results may be introduced that cannot be detected or accounted for. The primary objectives in statistical sampling are to obtain: 1) a random sample which has the same probability of being taken as any other sample of material, and 2) a sufficient number of samples to adequately characterize the material. Typically, the production of HMA is divided into lots of material; a lot being defined, for example, as 2000 tons. The lot is further subdivided into sublots of perhaps 500 tons for the 2000-ton lot. Random samples of HMA are then taken from each sublot and tested. This
approach
is called a stratified random sample, and it is the most commonly used method for construction material sampling. Besides HMA, it is also used for aggregates and asphalt binder.

In understanding statistical concepts, it is useful to examine how values from test data generally tend to arrange themselves. Most commonly, if one has enough data, they form a pattern like the one shown in Figure 1, where the most frequently occurring values fall around the center, and the values at the extremes are less frequent. If many, many tests were performed, a bell-shaped curve could be drawn through the tops of the bars and the resulting distribution of points is known as a “normal” distribution. It is called normal because many types of measurements of natural events result in this type of distribution, and the same is true of many engineering test results. If one has a smaller sample size of about less than 30 measurements, a Student distribution results, the characteristics of which are a larger variance but still a bell-shaped curve.

There are several statistical descriptors that can be used to define test data from construction projects. These are defined below:

**Mean** – The average of a series of numbers. In a normally distributed data set, it would be the number above which 50 percent of the values would occur.

**Variance** – Data dispersion found by adding the square of differences between individual data points and the mean and dividing this by the number of data points minus one.

**Standard Deviation** – Variability of a data group calculated by taking the square root of the variance. In a normal distribution, the mean plus or minus one standard deviation represents about 68 percent of the data set. The mean plus or minus two standard deviations represents about 95.5 percent of the data, and the mean plus or minus three
Risk Analysis

Also important in the use of statistics for specifications are the concepts of buyer’s and seller’s risks. Plainly put, the buyer’s risk is the probability that the buyer would accept material which is of an unacceptable quality on the basis of the test results. The point at which this risk occurs is referred to as the rejectable quality level (RQL). Conversely, the seller’s risk is the probability that good quality material would be rejected as unacceptable on the basis of the test results. This point is called the acceptable quality level (AQL). The buyer’s and seller’s risks can and should be defined in any statistical specification in terms of an Operating Characteristic (OC) Curve as shown in Figure 2. A point on this curve shows, for a given set of requirements, the probability of accepting a lot of material for a particular percent of values within limits. This varies according to the sample size and the allowable percent of defective material. AASHTO Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction, AASHTO Designation: R 9 states, “The importance of constructing OC curves cannot be overstated. In this manner, the risks to both the highway agency and the contractor can be determined in advance and, if necessary, modifications of the acceptance plan can be made before troublesome situations arise in the field.”

Unfortunately, the construction of OC curves and their presentation in specifications are not typical features as pointed out in a recent report by the University of Washington. Furthermore, it should be pointed out that when the buyer’s and seller’s risks are calculated in this fashion, it is only valid if the quality characteristic under consideration is independent of other quality characteristics being evaluated. For instance, asphalt content and layer thickness would be independent of each other and separate OC curves could be drawn for each. However, air voids and voids in mineral aggregate (VMA) are interdependent qualities since air voids are used in the calculation of VMA and so the development of OC curves as described by AASHTO R 9 is not appropriate. This will be described in detail later.

Sources of Variability

In order to properly apply statistical concepts, it is necessary to obtain representative samples from a given population. A population, in this instance, is represented by a material lot. The material in the lot should be manufactured under the same conditions, e.g., same aggregate, same asphalt, same asphalt content, etc. When questions arise concerning the appropriateness of this assumption, statistical testing of the data means and variances should be conducted to resolve the issue.

Variability is inherent in construction materials and it is the variability of material that statistical specifications are intended to limit. However, the variability of the material becomes intertwined with the variability associated with sampling and testing the material. A good specification is written such that the variability of the material is controlled within reasonable limits, while allowing for adequate sampling and testing variability.

If a sample of material to be tested is obtained improperly, it may not be representative of the material as a whole. For instance, if an aggregate is sampled consistently from one side of a stockpile, its gradation may be influenced by the wind blowing the finer particles to one particular portion of the pile. If a technician consistently obtains hot mix samples from the edge of a paved lane, segregation of the mix caused by the paver may influence test results for gradation and asphalt content. Such sampling variability is normally minimized by taking random samples, which helps to ensure that all the material has an equal chance of being sampled. However, practices by any given technician may result in some small amount of error being introduced in characterizing the material.

Testing variability may result when the same technician performs a test operation slightly differently or when different technicians perform a test method differently. This may be due to ambiguity in the way the method is written, a lack of guidance in performing certain operations, or using different equipment to perform a particular task. There are generally two measures of variability in performing test methods: within-laboratory and between-laboratory.
The goal of a statistical specification should be to limit the variability of materials and construction operations to the extent that this affects the performance and economics of the pavement. Being overly restrictive on the amount of variability allowed will increase the contractor’s risk of having suitable material rejected and unnecessarily increase the cost of the pavement. Being too lax on variability will increase the agency’s risk of accepting inferior material and will result in poor pavement performance. Thus, the amount of allowable variability in the material must be carefully balanced between the economics of the initial construction cost and the cost of early pavement rehabilitation.

Training and certification of technicians and accreditation of laboratories are essential in the process of quantifying and reducing sampling and testing variability. There are currently a number of efforts by industry groups and DOTs to regionalize the process of technician training and certification. This would allow greater uniformity in test methods across state lines, and it would allow agencies and contractors a better set of data from which specification limits could be adjusted. Laboratory accreditation is another mechanism that may be used in reducing testing variability. The AASHTO Materials Reference Laboratory maintains standards for laboratory testing equipment and test performance. Regular inspection and accreditation by such organizations help to ensure the maintenance of test standards on a national basis. The certification of technicians and the accreditation of laboratories should apply to both the industry and agencies in order to reduce disputes when comparing contractor and agency test results.

**Summary**

This article has presented some background on the history of specifications, a review of basic statistics, an explanation of buyer’s and seller’s risks and a discussion on sources of variability. This will serve as a foundation for the next HMAT article concerning Percent Within Limits specifications and statistical pitfalls.

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