Editor’s Note: This article is the third in a three-part series discussing the background, current state, and future of statistical specifications for Hot Mix Asphalt. The first article presented a historical background of specifications and an explanation of statistical concepts. The second article discussed Percent Within Limits specifications, issues in statistical approaches, and desirable features for specifications. This issue’s article deals with developments on Performance Related Specifications (PRS), the goal of which is to tie the end-result quality characteristics of a product to its performance by means of a mathematical model.

Introduction

In the past few issues of HMAT, statistical specifications have been discussed with a focus on the background, today’s practice, and potential pitfalls. This article will discuss the state of Performance Related Specifications (PRS).

According to a PRS workshop held in May of 2000: “A PRS is a specification that uses quantified quality characteristics and life-cycle cost (LCC) relationships that are correlated to product performance.”

The workshop went on to present a definition for management consideration: “A PRS is the bridge between construction quality and long-term performance.”

These relatively simple descriptions contain substantial technological implications. While the concept of basing payment upon expected performance is an admirable goal, it is essential in this type of specification that equations exist between pavement material properties and pavement performance. The accuracy of these models must be carefully evaluated if PRS is to be used in determining payment for a constructed pavement.

Background

Performance related specifications for highway construction have roots dating back to the early 1980s when the Federal Highway Administration (FHWA) launched its research program, Performance-Related Specifications for Highway Construction and Rehabilitation. An excellent National Cooperative Highway Research Program (NCHRP) synthesis on the state of PRS and its use was written by Chamberlin in 1995. He stated that PRS is not a means of improving performance as much as it is a method for determining the value added or lost according to the quality of the product weighed against its expected performance.

Beginning with work in the early 1980s, researchers expressed concern with the lack of performance data to develop models adequate for PRS. Along policy lines in this same time frame, the Transportation Research Board (TRB) steering committee on research and development gave high priority to PRS development, and the FHWA categorized PRS as a high priority national program area.

Researchers at Pennsylvania State University presented the basic foundation for Hot Mix Asphalt PRS in 1990. They pointed out that relationships between performance and material properties were lacking and that the Long-Term Pavement Performance (LTPP) program should provide these as one of its key missions. They also noted that performance equations should have been available somewhere in the time period of 1994 to 1996.

Another study, funded by FHWA, and concluded in 1992, gave the initial performance relationships that could be used in a PRS for asphalt mixtures. The equations related materials and construction characteristics to calculated pavement responses (i.e., stresses or strains in the pavement). These responses could then be used in previously developed performance equations to estimate pavement life. To investigate the accuracy of these models, a plan was developed to construct an accelerated pavement test track.

WesTrack was the test facility constructed to provide the needed link between HMA characteristics and pavement performance, first under FHWA and later under NCHRP Project 9-20. The test track had 26 original test sections and nine replacement sections of 6-inch thick asphalt pavements, over a 12-inch granular base layer, over an 18-inch engineered fill. A total of 4.9 million equivalent single axle loads were applied during a 40-month time period. Mixtures were varied in terms of gradation, asphalt content, and in-place densities. As will be discussed later, performance equations to predict fatigue cracking and rutting resulted from the WesTrack effort.

Current national research on PRS is being conducted under NCHRP Project 9-22, led by Fugro-BRE Consultants. This project, entitled Beta Testing and Validation of HMA PRS, began in October 2000 and will conclude in December 2003. The objectives of this research are to: 1) evaluate and refine the PRS developed at WesTrack in field trials, 2) calibrate and validate the WesTrack performance models, 3) develop a training course curriculum and training materials, and 4) perform trial implementation during actual construction.

Performance Predictions

Performance predictions are at the heart of PRS. However, the ability to predict pavement performance with any accuracy remains an elusive goal. There have been a number of studies to investigate pavement performance and subsequently develop equations to predict performance. Among the current efforts, the Strategic Highway Research Program’s LTPP study and the WesTrack experiment
represent two of the biggest efforts to define pavement performance. Although it is one of the key goals of LTPP to develop pavement performance models, to date models have only been produced for concrete pavements. Even to the extent of examining the impact of HMA material properties on performance, LTPP has only succeeded in attempting to improve methods of measuring resilient modulus in the laboratory and estimating the modulus in the field from deflection data through a technique known as backcalculation. If useable information for PRS is to emerge from LTPP, then correlations must be found between field-measurable properties such as density and engineering properties like resilient modulus. The resilient modulus, with other performance measures, must then be tied to pavement performance by an equation. The question then is whether the resilient or backcalculated modulus has a sufficient correlation to other methods of fundamental characterization such as the Simple Shear Test (SST) developed as part of the Superpave effort or the dynamic modulus test which is currently proposed as a simple performance test.

It is generally not practical to perform modulus measurements in the field at the time of construction. So, once a relationship has been established between some modulus value and performance, another must be found between modulus and field-measured material properties such as in-place density. The density would then be used to estimate the modulus, and the modulus would be used along with other variables to predict performance. The performance model would form the basis for calculating the economic impact of the quality of the HMA pavement.

Undertaking an effort to develop such performance models from the LTPP database would require a great deal of resources and time. Success in such an effort would be tied to the ability of the variables within the models to adequately explain the variability in performance. This, in turn, would be dictated by the magnitude of influence for other performance variables such as traffic and climate as well as the ability to accurately quantify them. As pointed out by FHWA, just the collection of accurate traffic data is very difficult, to say nothing of predicting performance.

The WesTrack study resulted in the development of performance equations for HMA. These equations were the result of observations of pavement distress made on the 26 original test sections. Mixtures were varied in terms of gradation, asphalt content, and in-place densities. The performance equations had the following forms for fatigue and rutting, respectively:
Both of these equations relate observed pavement distresses (dependent variables) to variables that include HMA mixture properties, traffic, and temperature. The HMA properties are those of complex modulus (fatigue cracking only), air void content, and asphalt content. The influence of these variables, which are under the control of the contractor, relative to those of traffic and temperature, which are external to construction, need to be quantified in any calibration effort. It is likely that traffic effects could overwhelm all other variables in pavement performance predictions.

The contractor-controlled properties shown in equations 1 and 2 are data obtained from materials testing. The nature of the testing, including methods of sampling, must be clearly defined so that there is no ambiguity between values used to develop the performance model and those obtained on a PRS construction project. Furthermore, the tolerance allowed on test results during construction must allow for the precision of the test methods in addition to the allowances made for production.

One must also consider the conditions under which equations 1 and 2 were developed. The fact that WesTrack was constructed and operated in a high desert environment means that errors will be inherent whenever the models are applied to pavements in other climates. It should also be remembered that WesTrack traffic loading occurred over a relatively short time, precluding the effects of weather and aging over a longer period. This means that the models will have to be developed for pavements in service and adjusted to fit the climate, materials, soils, etc. in a variety of conditions, perhaps even within the same state.

In the end, it is important to have a meaningful performance prediction, for without this, PRS is simply an end-result specification with a poor model to justify it. An example of a lack of fit between a model and actual pavement performance is shown in Figure 1. This figure is taken from a report on the development of a life-cycle cost procedure for the Ontario Ministry of Transportation. It shows a comparison between predicted and actual percent slab cracking in concrete pavements in Ontario, Quebec, and Wisconsin. The model was based upon the performance of concrete pavements in the LTPP study and an FHWA study of 303 concrete pavement sections in North America. It can be seen that in almost all cases, the model predicted cracking (up to 60 percent of slabs) when no cracking was observed, and it predicted no cracking when up to 30 percent of the slabs were cracked. If a performance related specification was based upon this model, a contractor or agency could justifiably question the basis for pay.

It should also be pointed out that slab cracking in a concrete pavement should be easy to predict relative to distress in a HMA pavement, because the primary predictive variables are load, slab thickness, concrete strength, and the stiffness of the underlying materials. In an HMA pavement, other considerations such as changes in stiffness with changes in temperature frequently confound the performance prediction.

**Summary**

As responsibility for the quality of HMA pavements continues to shift from the specifying agency to the contractor, it will be critical to better understand the relationships between characteristics of the mixture and the expected pavement performance. However, it must be understood that the performance also depends upon the conditions imposed by the traffic, climate, and underlying materials.

PRS is a very desirable goal, but there are important technical issues to address with the current statistical specifications first. These issues need to be resolved as progress is made in

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**Equation 1: Fatigue**

\[ FC = \alpha_1 + \alpha_2 \ln(ESAL) + \alpha_3 \ln(\epsilon) + \alpha_4 \log(E^*) + \alpha_5 P_{asp} + \alpha_6 V_{air} \]

**Equation 2: Rutting**

\[ \ln(rd) = \alpha_1 + \alpha_2 \ln(ESAL) + \alpha_3 P_{asp} + \alpha_4 V_{air} + \alpha_5 T \]

**Where:**

- FC = percent fatigue cracking in the wheel paths,
- \( \alpha_1 \) = regression coefficient,
- ESAL = number of equivalent single axle loads,
- \( \epsilon \) = bending strain at the bottom of the asphalt concrete,
- \( E^* \) = complex modulus of asphalt concrete,
- \( P_{asp} \) = asphalt content,
- \( V_{air} \) = air void content,
- \( b \) = regression equation exponent,
- \( rd \) = rut depth, and
- \( T \) = average temperature to time of rut depth measurement.

**Figure 1.** Relationship between Actual and Predicted Concrete Slab Cracking from Ontario Life-Cycle Cost Study. (Smith, K.L., N.G. Gharibeh, M.I. Dartor, H. Von Quintas and B. Killingsworth, Review of Life-Cycle Costing Analysis Procedures, Final Report, Ministry of Transportation of Ontario, December 1998)