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LRRB
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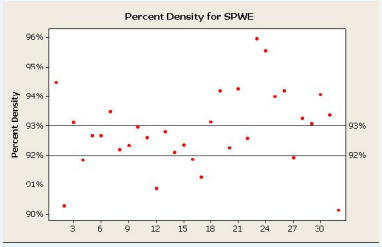
PROJECT COST:

$94,876



This scatter plot of percent density for two sample lots includes reference lines at the 100 percent pay factor limits. Densities at or above these reference lines indicate high-quality work for the pavement mix being tested.

MINNESOTA DEPARTMENT OF TRANSPORTATION

RESEARCH SERVICES SECTION

Statistical Methods for Materials Testing

What Was the Need?

State departments of transportation use a variety of testing protocols to assess the quality of contractors' work in the construction and rehabilitation of pavements. Mn/DOT uses one of these tests to determine the quality of compaction effort and provides incentives to contractors who achieve a high relative density in hot-mix asphalt pavement construction.

Mn/DOT's current density testing protocol for HMA divides the daily amount of pavement built by each contractor into a small number of lots. Core samples are taken from two locations in each lot, and lab tests are used to determine the relative density of each sample. The average of the two values is used as an estimate of the lot's relative density, which determines the lot's pay factor (the incentive or disincentive payments to the contractor based on the mean density of each lot). For example, a pay factor of 102 percent results in a 2 percent incentive per ton, and a 95 percent pay factor penalizes the contractor by 5 percent per ton.

It is important to employ the optimum number of tests for determining the accepted level of quality. Too few samples increase the probability of assessing an incorrect pay factor; too many samples increase testing costs and weaken the pavement. To make good payment decisions, Mn/DOT needed a reliable method to determine the number of test samples required to accurately apply the pay factors associated with the ranges of density values.

What Was Our Goal?

The goal of this study was to develop a testing protocol to determine the required number of samples that should be tested based on user-specified criteria to make more reliable pay factor calculations. A second aim was to develop guidelines for estimating key parameters needed to implement the testing protocol.

The project was not designed to propose changes to the way density values are themselves computed for a given sample or to evaluate current formulas for determining pay factors from relative density, but only to determine how many samples are needed to determine a pay factor.

What Did We Do?

Researchers reviewed current testing protocols and used Bayesian statistics to devise methods for determining how many core samples need to be evaluated using historical data about the contractor's work and reliability measures specified by the project owner as inputs.

In brief, the protocol requires dividing the range of relative densities into equal-sized intervals called bins so that each bin lies within a single pay factor range, then evaluating individual samples one by one, putting them into the appropriate bin, until the reliability measures have been met. A cutoff ratio of .6 and cutoff point of 2 means that the testing procedure will terminate when only two bins are at least 60 percent as likely as the most likely bin as calculated from the sample inputs.

Researchers developed two variations of this testing protocol to provide DOT project engineers with decision support:

- The first testing variation uses core samples, tested later in the lab, to determine pavement density where the number of tests must be known before any samples are

continued

"This new approach to testing can help Mn/DOT apply more accurate incentive and disincentive payments and reward contractors that are doing more than just meeting the minimum specifications."

–Tom Ravn,
Director, Mn/DOT Office of Construction and Innovative Contracting

"With the new testing protocol, the project owner can set the criteria to determine how many samples should be taken to achieve a desired level of accuracy in identifying mean lot density."

–Diwakar Gupta,
Professor, University of Minnesota Institute of Technology, Industrial & Systems Engineering

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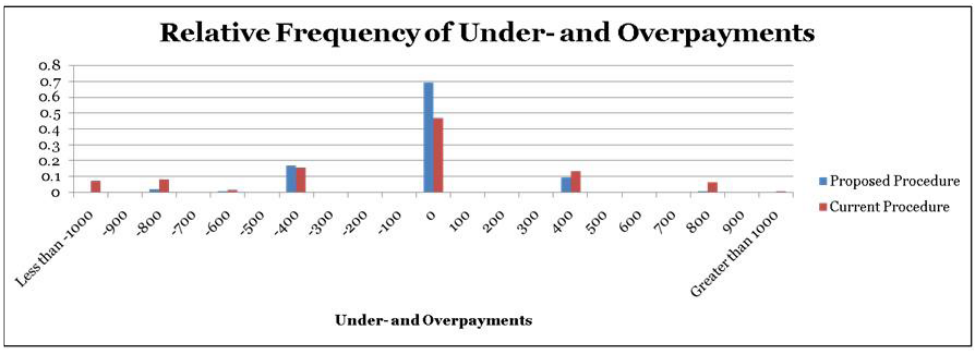

This graph shows the relative frequency of under- and overpayments in the current and proposed testing procedures.

obtained. A computer program calculates the number of samples that should be tested for the lot based on the reliability criteria. Test results are entered in an Excel worksheet that determines the pay factor.

- The second variation addresses testing in the field, where density observations are available immediately, for example, with the use of a nuclear density gauge that records how gamma radiation interacts with the electrons in the pavement to determine pavement density. An Excel spreadsheet uses the same data used in the first variation, augmented by the observed relative density from each test as it is taken in the field. With each test, the Excel worksheet recommends whether at least one more sample is needed to achieve the desired reliability or the procedure should terminate.

Researchers also developed a procedure to determine the initial estimate of variance of density value for each new contractor and identify when that value should change based on actual contractor performance.

What Did We Learn?

Researchers compared current and proposed testing procedures and found that the proposed testing procedure resulted in more accurate pay factor calculations. Using an example based on historical data, accuracy increased from 47 percent to 70.6 percent, where accuracy is measured by the proportion of times that the correct pay factor is identified. This translated to a change from an average over- and underpayment of $109.60 and $287.33 per lot to $44.50 and $90.74 per lot, respectively.

What's Next?

Mn/DOT continues to look for ways to improve pavement quality, and this research provides an avenue for further discussion about possible changes to specifications for materials testing. Future activities may involve providing training to contractors on the use of the new testing protocol with nuclear density gauges in the field.

This Technical Summary pertains to Report 2009-41, "Statistical Methods for Materials Testing," published December 2009. The full report can be accessed at http://www.lrrb.org/PDF/200941.pdf.