Development of End-Result and Performance-Related Specifications for Asphalt Pavement Construction in Illinois

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Illinois has been engaged in research over the past decade to develop quality control/quality assurance (QC/QA) specifications that maximize pavement construction quality, while minimizing the amount of agency testing required to execute the system. This paper describes recent efforts to develop and implement end-result and performance-related specifications (ERS/PRS) in Illinois. In the summer of 1996, a pilot study was conducted during the construction of an eight-inch overlay placed over rubblized concrete on Interstate 57 near Edgewood, Illinois, to collect data to support the development of ERS/PRS. A high sampling and testing frequency was followed to aid in the determination of typical variances and to help determine the minimum amount of samples required for QC and QA in the future. Fundamental properties of plant produced mixtures were also measured, including: fatigue, permanent deformation, resilient modulus, and tensile strength. Furthermore, a unique "properties map" was developed, where all measured quality characteristics for each sublot of material were mapped by station and by pavement lift. This map will facilitate the development of future linkages between quality characteristics, engineering properties, and measured distresses (rutting, cracking, moisture damage, etc.), which is essential for the development of a comprehensive PRS. Ongoing and planned research efforts in this area are also described, including an upcoming project involving the development and use of percent-within-limits (PWL) based pay factors for field density control, which utilize contractor test results, and the evaluation of a rapid, non-nuclear pavement density gauge. Key words: quality control, quality assurance, performance-related specifications, end-result specifications, asphalt pavement.

INTRODUCTION

Quality assurance specifications are an important component of an organization's commitment to overall quality management, and consist of several activities, including: process control, acceptance, and sometimes, independent assurance of a product. Specifications for the construction of asphalt pavements can generally be classified into method-related specifications (MRS), end-result specifications (ERS), performance-related specifications (PRS), or combinations thereof (Figure 1). Method specifications give a set of procedures, or "recipe," that if followed by the contractor, will result in full payment for the constructed facility. This places a great deal of responsibility and testing burden on the agency rather than the contractor. End-result and performance-related specifications, as their names imply, require a contractor to achieve specified as-produced or as-constructed quality levels, which are ideally linked to the attainment of good future performance. These types of specifications shift most or all of the responsibility for producing a high quality product to the contractor, and should ideally offer the contractor complete freedom in the methods used to arrive at these quality levels.

Performance-related specifications are difficult to develop, but offer the ultimate means of compensation for a delivered product: variable payment (incentive/disincentive) can be assigned based upon expected performance and increase/reduction in life cycle value of the product relative to the design life cycle worth. As illustrated in Figure 2 (Shook [*1*]), the development of a PRS involves having links between quality characteristics (asphalt content, gradation, density, etc.), engineering properties (modulus, tensile strength, etc.), and performance (distresses, serviceability level). Obviously, the development of these links, particularly the secondary relationships between quality characteristics and engineering properties, can be very difficult since they are material dependent and many complicated interactions exist. Furthermore, one must also consider variability in measuring equipment, operator errors, and typical material variances during production (resolution of the inputs) when deciding on the required accuracy and therefore complexity of the secondary relationship models. As a result, it is most practical to develop a specification with the combination of ERS and PRS elements commensurate with existing technologies, local materials, and test equipment.

Overview

This goal of this paper is to:

1. Describe the philosophy for moving towards ERS and PRS in Illinois
2. Describe the Edgewood 1996 Pilot Project Conducted to Support Development of ERS/PRS in Illinois
3. Outline Upcoming Projects and New Technologies Being Evaluated for ERS/PRS Development

PHILOSOPHY FOR MOVING TOWARDS PERFORMANCE-RELATED SPECIFICATIONS

Because existing primary and secondary relationships preclude the direct movement to PRS, the following staged approach has been developed for gradual movement from the existing MRS/ERS sys-

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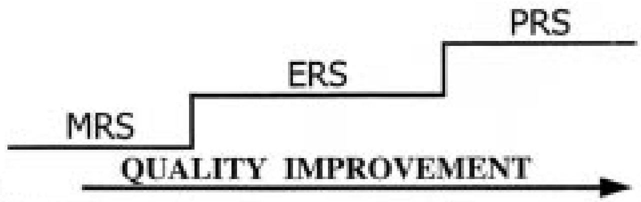

Characteristic			
Specification Variables	Indirectly or directly related to performance	Indirectly or directly related to performance	Only those directly related to performance
Raw Materials	Agency	Agency	Contractor
Mix Design	Agency	Contractor	Contractor
Process Control	Agency/Contractor	Contractor	Contractor
Lots	No	Yes, uniform construction run	Yes, same for all characteristics
Sampling	"Representative" or arbitrary, frequency based on opinion	Random locations, frequency based on sampling theory	Random locations, frequency based on sampling theory
Pay Adjustments	Usually not used	Often used. Based on judgement.[1]	Required. Based on performance and LCC analysis.[2]
Type of Acceptance Tests	May or may not be related to performance	May or may not be related to performance	Directly related to performance (prediction models)
Material Acceptance	By agency, often from a single sample	By agency, from samples obtained prior to placement or in-situ	By agency, from samples obtained in-situ
Equipment	Agency specifies	Agency allows wider range of equipment usage	Few proscriptions

[1]Considers variation in quality characteristics directly. Pay adjustment factors for individual quality characteristics, must combine into one pay factor.
[2]Considers variation in quality characteristics directly. Pay adjustment factors for quality of lot, not individual characteristics.

FIGURE 1 Evolution and advantages of end-result and performance-related specifications (after Patel [*5*]).

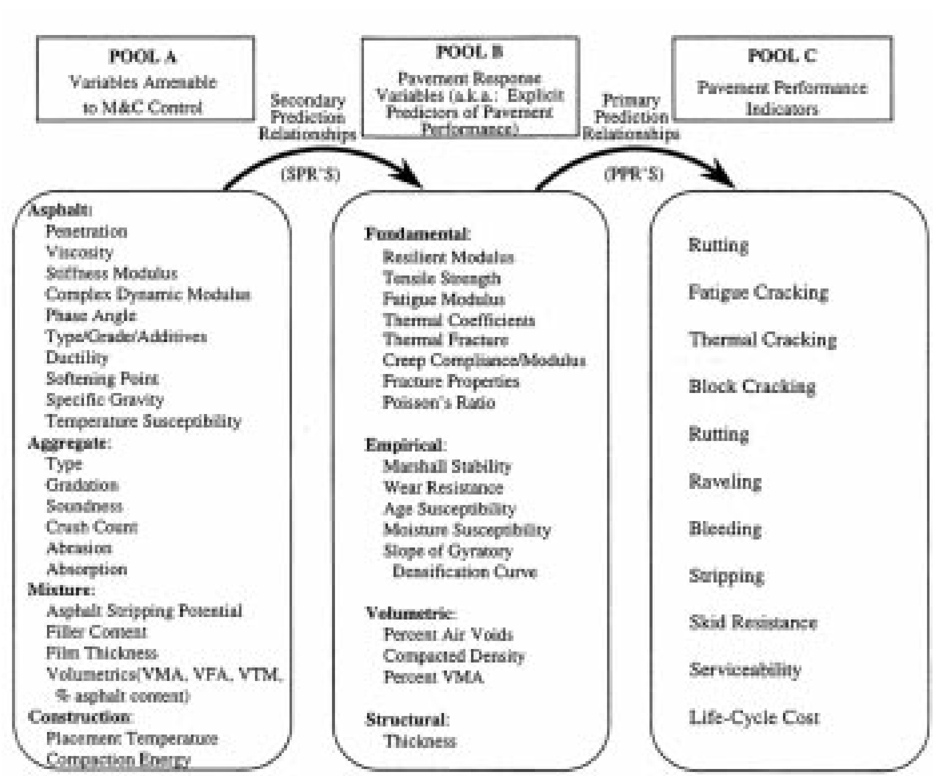

FIGURE 2 Connection among variables associated with an asphalt concrete pavement surface PRS (after Shook [*1*]).

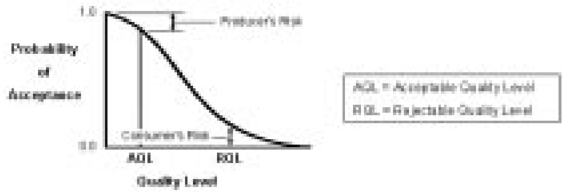

FIGURE 3 Operating characteristics curves (after Afferton et al. [*3*]).

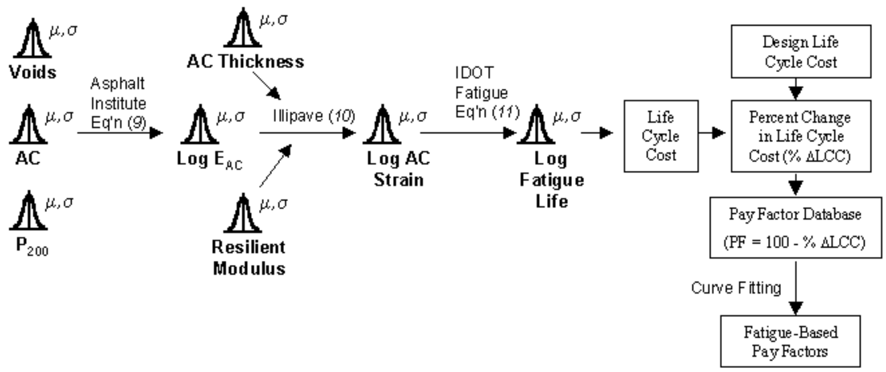

FIGURE 4 Framework of a performance-related pay factor for fatigue (after Patel [*5*]).

tem to a predominantly end-result specification. As primary and secondary relationships become available, the ERS will then be modified to contain as many PRS elements as possible. The key steps in this development have been identified as:

1. *Make an initial move to statistical QC/QA.* The AASHTO Quality Level Analysis (*2*), involving Percent-Within-Limits (PWL) based pay factors is now being used as a variable payment scheme for pavement thickness in Illinois. A demonstration project is also being developed to evaluate a PWL-based pay factor for field density for the summer of 1998, which is described later in this paper.
2. *Develop a comprehensive ERS to consider all relevant quality characteristics.* Develop pay factors for other quality characteristics that are likely to relate to performance (asphalt content, gradation, etc.). Use QC/QA and performance data from past projects along with engineering experience to establish rational specification limits and pay factors. Use operating characteristics curves (Afferton et al. [*3*]) to evaluate and adjust pay factors so that risks are balanced fairly between the contractor and agency (Figure 3).
3. *Monitor and foster development of primary and secondary prediction relationships.* A pilot field study was initiated in 1996 at Edgewood, IL (Buttlar et al. [*4*]), which will provide a comprehensive database for the development of these relationships. This project is described in detail later in this paper. The progress of other related studies, such as WesTrack and National Cooperative Highway Research Program (NCHRP) project 9-15, will be monitored and relevant findings will be incorporated to the extent possible.
4. *Develop performance-related pay factors.* A system was developed in IDOT ICHRP IHR-425 by Patel (*5*) to generate pay factors for full depth asphalt pavements based upon fatigue cracking (figure 4). The variable pay factor developed was based upon the change in life cycle costs associated with departures from design means and standard deviations of selected quality characteristics. The effects of these deviations on engineering properties were considered simultaneously using the Monte Carlo simulation model, which were in turn used to predict pavement response and fatigue life. However, additional pay factors must still be developed for other distresses, such as rutting, thermal cracking and moisture damage, and for other flexible pavement systems (conventional and overlays).
5. *Compare performance-related pay factors with ERS pay factors, which were developed based upon experience.* Choose the more conservative pay factor, if applicable, or develop a new pay factor that combines the most conservative elements of each of the two.
6. *Periodically repeat steps 3, 4, and 5 to move from ERS to PRS.* The move from ERS to PRS will take considerable time, and there will always be room to reevaluate and improve the accuracy and practicality of the system components. Therefore, periodic cycling through steps 3 through 5 will be necessary.

The following section will describe a pilot field study conducted in the summer of 1996 at Edgewood, Illinois, which was established to generate data to support the development of primary and

TABLE 1 Comparison of Pilot Study QC Test Program and IDOT's Superpave Demo Project QC Plan

Parameter	Frequency of Tests		Test Method
	IDOT Superpave QC	**Pilot Study**	
	Mixture Control Testing		
Aggregate Gradation Hot bins for batch and continuous plants. Individual cold-feeds or combined belt-feed for drier-drum plants (% passing 12.5-mm [1/2-in], 4.75-mm [No. 4], 2.36 mm [No. 8], 600-µm [No. 30], 75-µ [No. 200] sieves)	Two dry gradations per production day Washed gradations performed on every eighth test	Four dry gradations per productions day Four washed gradations per production day	Illinois Procedure (See currrent Department Aggregate Technician Course workbook.)
Asphalt Content by Ignition Oven	Two per production day	Four per production day	Illinois Modified AASHTO TP 53-pending
Air Voids Bulk Specific Gravity of Gyratory Sample Bulk Specific Gravity of Marshall Hammer Maximum Specific Gravity of Mixture	1 per half day of production for first 2 days and 1 per day thereafter (first sample of the day)	Four per production day	*Per the Department's "Superpave Field Control Course" Illinois-Modified AASHTO T 166 Illinois-Modified AASHTO T 209
Field VMA	1 per half day of production for first 2 days and 1 per day thereafter (first sample of the day	Four per production day	Per the Department's "Superpave Field Control Course"
	Field Control Testing		
Field Density	800-m Lot Size: IDOT: 5 Transverse Measurements at One Location within Lot	800-m Lot Size: Stratified Random Measurements in Each of 4 Equal, 200-m Sublots (Random Longitudinal and Transverse Position within Sublot)	Per the Departments Illinois-Modified ASTM D 2950, Standard Test Method for Determination of Density of Bituminous Concrete In-Place by Nuclear Method"

*For each of the four daily sublot samples, two gyratory tests were performed: one to N_{des} gyrations and one to N_{max} gyrations.

secondary performance relationships for Illinois materials and construction (step 3 above).

THE 1996 PILOT FIELD STUDY AT EDGEWOOD, ILLINOIS

A pilot field study to collect data in support of ERS/PRS development was conducted in concert with rehabilitation of Interstate 57, in south-central Illinois, during the summer of 1996 (*4*). Some of the pertinent project features include:

- Location: IDOT District 7, about 12 miles south of the I-70 crossing at Effingham
- Project length: 4.3 miles, both northbound lanes of I-57
- Mainline paving: July 26-August 20, 1996; contractor: Howell Paving Co.
- 8-inch HMA overlay, 27,000 tons; batch plant: Effingham, IL., 2000 tons/day
- Overlay placed on 8-inches of rubblized CRCP (Antigo Construction, multiple-head breaker)

The goals of the pilot study, some of which are ongoing, were to:

- Foster end-result specification (ERS) development for ACP construction in Illinois, and explore sampling and testing schemes

suitable for statistically-based QC/QA, including: 1) clear LOT and SUBLOT definitions for as-produced and as-constructed asphalt mixtures; 2) random sampling protocols, and; 3) evaluation of a modified field density sampling procedure, which was more suitable for statistically-based QC/QA than the existing method
- Provide data for the evaluation of percent-within-limits (PWL) based pay factor concepts, including; 1) establishing baseline variability for new test procedures; 2) determining minimum sample sizes, and; 3) evaluating suitability of gyratory compactor and ignition oven for QC
- Establish possible links between QC measurements/ AC engineering properties/ and performance, by: 1) measuring fundamental properties on LOT samples; 2) monitoring pavement profile, structural layer properties, pavement distresses, and overall serviceability, and; 3) correlating quality characteristics, engineering properties, and performance for given LOTS of material.

QC/QA Testing Program at Edgewood

Part of the research effort was to study typical variances for new test devices and to determine optimum test frequencies for QC/QA in general. Therefore, additional tests were supplemented with the QC testing specified in IDOT's Special Provision for QC/QA of Class I Bituminous Concrete Mixtures (*6*), as shown in Table 1. In accordance with IDOT's QC testing plan for Superpave Demo Projects, air voids were monitored at the plant with a Troxler Superpave Gyratory Compactor. Asphalt content was obtained in conjunction using an NCAT binder ignition oven, and aggregate gradation was controlled through dry sieve analysis of ignition oven residue. Construction control testing was limited to the determination of field density using the nuclear gage. An extended testing program was implemented at Edgewood, which consisted of diametral creep tests, split tensile tests, resilient modulus tests, beam fatigue tests, and triaxial testing. Also conducted were Georgia loaded wheel tests and Superpave indirect tensile tests (IDT).

Sampling and Lot Definitions

Central to the development of a statistically-based QC/QA ERS/PRS specification is having a sound random materials sampling and testing procedure. For the control of as-produced quality characteristics, A LOT was defined as one day of mixture production. Each LOT was further subdivided into four SUBLOTS. The exact sampling time for each sublot was found by multiplying separate randomly generated numbers by the length of time of each sublot and adding the resulting time to the beginning of each sublot.

For the control of as-constructed quality characteristics, a LOT was defined as 800 meters of paved roadway, which was then subdivided into four 200-meter SUBLOTS. Field density readings were collected using a nuclear density gage, following two sampling methods (Figure 5). The first method was IDOT's existing density sampling scheme consisting of five transversely-aligned density measurements taken at one randomly determined location in each designated LOT. Samples were taken at 0.61-m (2-ft) intervals across each lane slightly staggered from perfect alignment perpendicular to the direction of traffic. The second method consisted of a single density measurement taken at a random location in both the transverse and longitudinal directions within each SUBLOT (200-m section).

Properties Maps

Figure 6 is a "property map" of the northbound I-57 driving lane. Crosshatched sections represent a LOT of material with the LOT number and thickness and type of lift placed in the top left corner. Within each of those sections are four subsections representing the four SUBLOTS associated with each LOT. The locations of the SUBLOTS were determined using quantities found on daily plant reports, lift thicknesses, mixture density, and field notes indicating times and locations of the contractorís density QC measurements. The SUBLOTS are numbered sequentially in the order they were produced. Dashed lines denote the estimated SUBLOTS boundaries. Percent-Within-Limits (PWL) were computed for asphalt content, percent passing the #200 (0.075-mm) sieve, and plant-measured air voids (*4*). The results of these calculations are shown for each LOT of material.

Selected Results from Edgewood Pilot Study

A comprehensive description of the Edgewood project findings to date can be found in Buttlar et al. (*4*). Two of the most prominent findings from the study related to as-produced and as-constructed mixture properties are presented in Figures 7 and 8. Figure 7 illustrates that the modified density scheme (Figure 5) appears to give a more representative assessment of overall LOT density, as denoted by the lower standard deviation of the moving average and hence flatter curve. Figure 8 illustrates the differences observed between air voids back-calculated from N_{max} to N_{design} gyrations in the Superpave gyratory compactor to air voids measured directly at N_{design}. Errors in predicted air voids at the design compactive effort of over 1.5 percent were measured during mixture production.

Alternate procedures were developed by Buttlar et al. (*4*) and Vavrik and Carpenter (*5*) to arrive at more accurate estimates of air voids at N_{design}. Vavrik and Carpenter also suggested the evaluation of mixture compaction characteristics based upon the "locking point," or the point during compaction at which the mixture exhibits a marked increase in resistance to further densification. The locking point has been found to be related to compaction tendencies in the field and its relationship to field performance is currently under investigation. Compacting a mixture past the locking point generally results in aggregate degradation that is not representative of field compaction, and thus, the benefit of compacting mixtures to N_{max} is currently being reevaluated on a national scale.

Future Monitoring of Edgewood Project

Performance monitoring of the Edgewood Pilot Project will consist of periodic (at least annual) measurement of rut depth, roughness, effective layer moduli (from falling weight deflectometer), distress mapping, and overall serviceability assessment. To develop primary and secondary links, it was necessary to take several measurements in each segment of pavement corresponding to various LOT combinations through the depth of the pavement. The vertical arrangement of LOTS in different layers is more aligned in the driving lane (Figure 6) than the passing lane (not shown). A

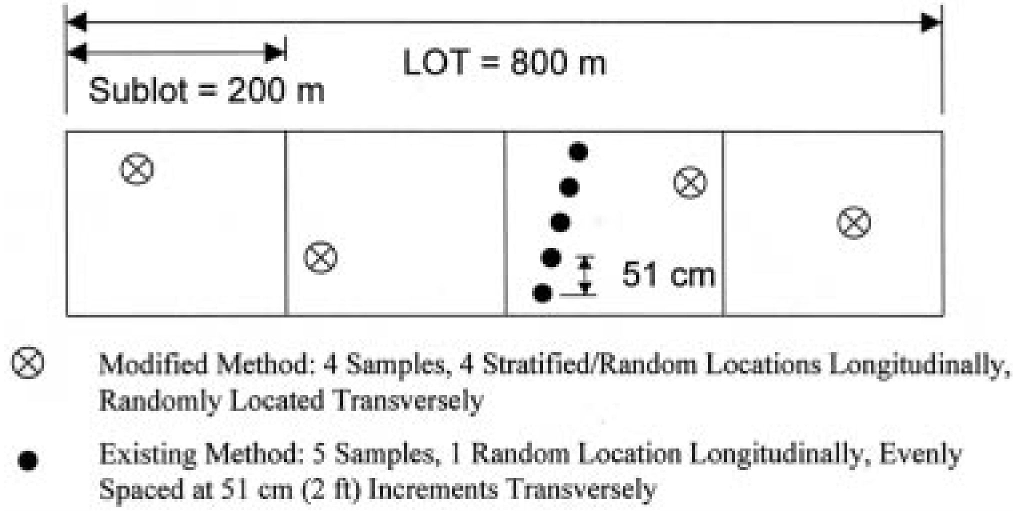

FIGURE 5 Comparison of density determination procedures: existing method versus modified method (from Buttlar et al. [*4*]).

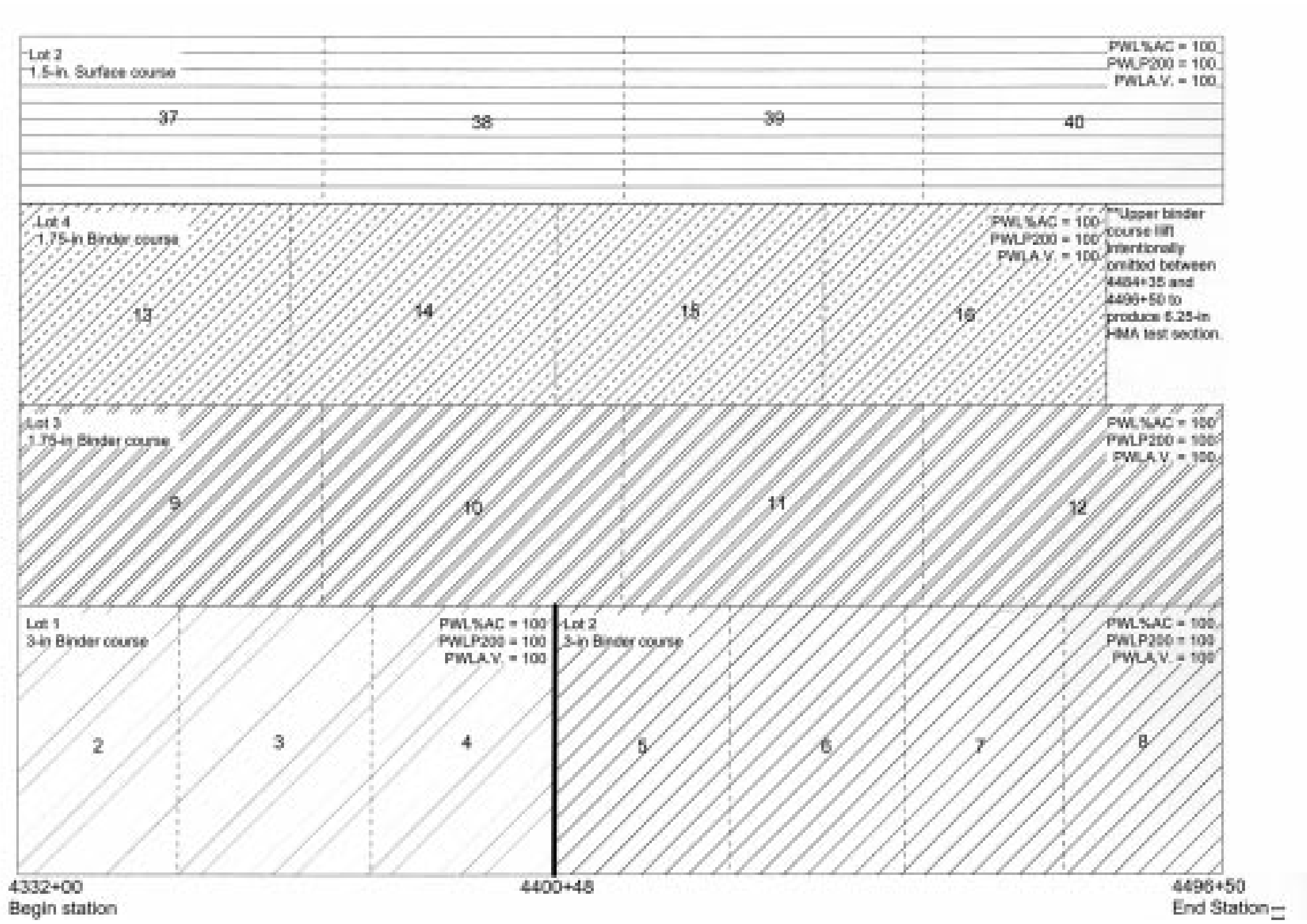

FIGURE 6 Property map for I-57 Edgewood pilot study: driving lane.

spacing of 200 feet between measurements was found to capture all possible LOT and most SUBLOT combinations.

Thus, the Edgewood pilot field study is one of the most comprehensive projects to date having plant, field, and engineering properties, a unique "properties map," and regular monitoring of performance. The study will provide valuable inputs for the development of ERS/PRS for asphalt pavement construction in Illinois.

UPCOMING PROJECTS AND NEW TECHNOLOGIES

A demonstration project is being developed for the summer of 1998 to:

- Showcase new ERS concepts for asphalt pavement construction in Illinois, including a PWL-based pay factor system
- Implement actual pay factors (PWL-based incentives/disincentives) to fully bring to light the practical implications of developing and implementing such as system

It was decided that actual pay adjustments would be limited to a single quality characteristic at first, namely field density. Other quality characteristics and pay factors will be monitored and tracked on a more casual basis to assess their feasibility for future revisions of the specification. It was felt that "real-time" information regarding PWL and pay factors should be readily available to contractors and agency personnel in the field. While the computation of PWL is not difficult, neither is it straightforward; it requires statistical tables and computations of standard deviations. This procedure is too cumbersome to be carried out by the quality inspector in the field, so the procedure was programmed into a Texas Instruments TI-85 calculator. Non-central t-distribution tables (*2*) had to be fit with polynomial prediction equations, since programming the calculator to interpolate the large tables would have been extremely cumbersome.

Other elements of the new ERS being developed for the demonstration project include:

- Use of contractor data as part of quality assurance and PWL-based pay factors, since the minimization of agency testing burden is a top priority in Illinois and most other agencies
- Dispute resolution and retest provisions, as these are perhaps as or more critical than the end-result property specification itself

Also to be investigated in the demonstration projects will be the following cutting-edge concepts and equipment:

- Monitoring of the "locking point" of the asphalt mixture during production.
- A triaxial-based QC/QA machine, developed by Industrial Process Controls (IPC), will be used to obtain fundamental properties of as-produced mixtures related to rutting and fatigue potential.
- The Superpave Indirect Tensile Test (IDT), developed by Roque and Buttlar (*8*) during the Strategic Highway Research Program, will be used to evaluate the change in predicted thermal cracking performance with respect to changes in quality characteristics measured during production.
- A non-nuclear pavement density gage, manufactured by Trans-Tech, Inc., will be run parallel to the nuclear gage and compared to densities as determined by coring and lab testing. The gage is measures the dielectric constant of the mixture, which is correlated to pavement density through a simple calibration procedure. The principle advantages of the device is the speed of measurement (a few seconds per reading) and the elimination of nuclear licensing and detailed training needs.

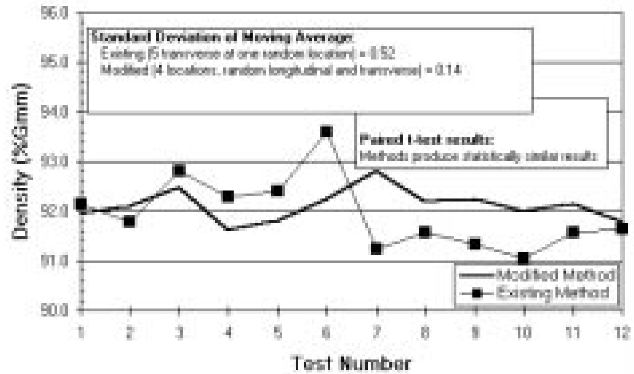

FIGURE 7 Comparison of density results at Edgewood: existing and modified methods.

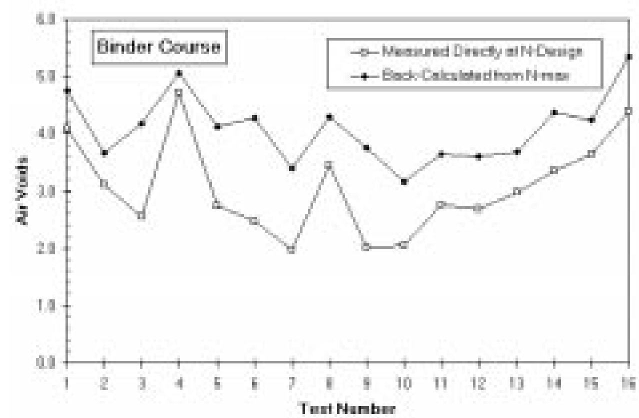

FIGURE 8 Difference between back-calculated voids and voids measured directly at N_{design}.

SUMMARY

The key points of this paper can be summarized as follows:

1. Performance-related specifications can be challenging to develop, but offer the ultimate means of compensation for a delivered product.
2. It is most practical to develop a specification with the combination of ERS and PRS elements commensurate with existing technologies, local materials, and test equipment. A staged approach for gradual transition to performance related specifications for asphalt pavement construction in Illinois was presented.
3. The Edgewood pilot field study is one of the most comprehensive projects to date having plant, field, and engineering properties, a unique "properties map," and regular monitoring of per-

formance. The study will provide valuable inputs for the development of ERS/PRS for asphalt pavement construction in Illinois.

ACKNOWLEDGMENT/DISCLAIMER

This work is based on the results of Project IHR-425, Evaluation of Potential Applications of End-Result and Performance-Related Applications of End-Result and Performance-Related Specifications. IHR-425 is sponsored by the Illinois Department of Transportation.

The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation, nor does it constitute a standard, specification, or regulation.

The authors would like to acknowledge the guidance and assistance provided by IDOT District 7 and Howell Paving Company, Inc., with sampling and testing of materials during the I-57/ Edgewood Pilot Field Study.

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