Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures:

Maine Department of Transportation (MaineDOT)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AMPT	Asphalt Mixture Performance Tester
ASTM	American Society for Testing and Materials
DOT	Department of Transportation
BMD	Balanced Mix Design
FHWA	Federal Highway Administration
HWT	Hamburg wheel tracker
HWTT	Hamburg wheel-tracking test
ILS	interlaboratory study
JMF	job mix formula
NCHRP	National Cooperative Highway Research Program
NETC	New England Transportation Consortium
NETTCP	Northeast Transportation Training and Certification Program
NMAS	nominal maximum aggregate size
PEP	Performance Engineered Pavements
PG	Performance Grade
QA	quality assurance
RAP	reclaimed asphalt pavement
SHA	state highway agency
SHRP	Strategic Highway Research Program 2
SIP	stripping inflection point
SSR	stress sweep rutting
U.S.	United States
VFB	voids filled with binder
VMA	voids in mineral aggregate

BACKGROUND

Balanced mix design (BMD) is one of the programs that supports the Performance Engineered Pavements (PEP) vision of the Federal Highway Administration (FHWA) that unifies several existing performance focused programs. This vision incorporates the goal of long-term performance into structural pavement design, mixture design, construction, and materials acceptance. In November 2019, FHWA published FHWA-HIF-20-005 Technical Brief, *Performance Engineered Pavements*. It provides an overview of the several initiatives that encompass the concept of PEP.

The BMD combines binder, aggregate, and mixture proportions that will meet performance criteria for a diverse number of pavement distresses for given traffic, climate, and existing pavement conditions. In December 2019, FHWA published FHWA-HIF-19-103, *Index-Based Tests for Performance Engineered Mixture Designs for Asphalt Pavements*. This informational brief provides practitioners with information about index-based performance tests that can be implemented within a BMD process.

In August 2018, the National Cooperative Highway Research Program (NCHRP) Project 20-07/Task 406, *Development of a Framework for Balanced Mix Design*, included a draft American Association of State Highway and Transportation Officials (AASHTO) Standard Practice for Balanced Design of Asphalt Mixtures with a nine step process for evaluating and fully-implementing a performance test into routine practice. The AASHTO Standard Practice describes four approaches (A through D) for a BMD process. The following is a brief description of the four approaches:

- ***Approach A, Volumetric Design with Performance Verification***. The Superpave asphalt mixture design at the optimum asphalt binder content determined in accordance with AASHTO R35 should meet the additional performance test criteria.

- ***Approach B, Volumetric Design with Performance Optimization***. Adjustments by up to plus or minus 0.5% for the preliminary asphalt binder content may be determined in accordance with AASHTO R 35 to meet the target performance test criteria.

- ***Approach C, Performance-Modified Volumetric Design***. AASHTO R 35 is used through the evaluation of trial blends to establish a preliminary aggregate structure and asphalt binder content. Performance testing is then used to adjust either the preliminary binder content or mixture component properties or proportions in order to meet the target performance test criteria. In this approach, the final asphalt mixture design is primarily focused on meeting performance test criteria and may not have to meet all Superpave volumetric criteria.

- ***Approach D, Performance Design***. Asphalt mixture components and proportions are established and adjusted based on performance analysis with limited or no requirements for volumetric properties. Minimum requirements may be set for asphalt binder and aggregate properties. Once the asphalt mixture properties measured using laboratory performance tests meet the performance criteria, the asphalt mixture volumetric properties may be checked for use in production.

The process identified in NCHRP Project 20-07/Task 406 involves nine essential steps for moving a performance test from concept to full implementation:

(1) Draft test method and prototype equipment.
(2) Sensitivity to materials and relationship to other laboratory properties.
(3) Preliminary field performance relationship.
(4) Ruggedness experiment.
(5) Commercial equipment specification and pooled fund purchasing.
(6) Interlaboratory study (ILS) to establish precision and bias information.
(7) Robust validation of the test to set criteria for specifications.
(8) Training and certification.
(9) Implementation into engineering practice.

While some of these nine steps can be adopted directly by a state highway agency (SHA) based on the level of effort completed regionally or nationally (e.g., steps 1, 4, and 5), others would need to be checked, expanded or redone using available (local) materials (e.g., steps 2, 3, 6, and 7). Steps 8 and 9 would need to be done by each SHA as part of its full implementation effort.

There is widespread recognition and desire by SHAs and the asphalt paving industry to use performance testing to complement volumetric properties to help ensure satisfactory pavement performance. Some SHAs have used the BMD process as part of mixture design and acceptance on select demonstration projects or have well developed BMD specifications, performance test methods and practices in place. These SHAs have valuable experiences and lessons learned that can facilitate the implementation of a BMD process or a performance test of asphalt mixtures into practice to improve long-term pavement performance.

OBJECTIVE

The primary objective of this overall effort was to identify and put forth positive practices used by SHAs when implementing BMD and performance testing of asphalt mixtures. To accomplish this objective, information was collected through site visits and other means with seven key agencies. Maine Department of Transportation (MaineDOT) graciously agreed to host a virtual site visit.

SCOPE AND OUTCOMES

The scope of each virtual site visit included: a pre-visit kickoff web conference and review of agency documents (policy, specifications, research reports, etc.); and a two to four-day virtual site visit to obtain detailed understanding of agency best practices and lessons learned for BMD and performance testing of asphalt mixtures that can facilitate the implementation of a BMD process into practice at other SHAs. The outcomes of each virtual site visit were to include:

1. A brief report to each FHWA Division Office and SHA visited on the observations and any recommendations identified.
2. A summary document of positive practices compiled from specific reviews in all of the SHAs visited.
3. A short, informational brief with the key highlights.
4. An accompanying PowerPoint presentation.

5. Depending on observations, research need statements may be developed for consideration.

This document is the brief report on the observations and recommendations identified through the MaineDOT virtual site visit.

GENERAL INFORMATION SPECIFIC TO MaineDOT

MaineDOT's goal is to tie asphalt mixture design to pavement structural design and pavement performance. The long-term plan is to evolve quality assurance (QA) specifications into performance specifications using proper performance tests. MaineDOT's initial foray into performance testing was to address an immediate need with premature failure of asphalt mixtures throughout the state due to raveling.

Performance testing of asphalt mixtures was regarded as a viable resource for MaineDOT to promptly address the observed pavement failures; in large due to positive experiences from other SHAs which correlated performance test results with field measured performance data. Field validation and correlation of performance test results with measured field performance data was one of MaineDOT's motivations for implementation of performance tests.

In 2010, MaineDOT purchased its first Asphalt Mixture Performance Tester (AMPT) to collect engineering properties for mixture evaluation and pavement structural design. The original purpose was to conduct dynamic modulus and flow number (AASHTO T 378) tests and to establish a database of measured values for reheated plant-produced asphalt mixtures that can be used as Level 2 inputs for the AASHTOWare Pavement ME Design software.

Few years later, MaineDOT was introduced to the direct tension cyclic fatigue and stress sweep rutting (SSR) tests that they considered to be used for higher profile paving projects. For the past 3 to 4 years, MaineDOT has been conducting these tests on the AMPT and collecting data on their asphalt mixtures to identify factors that are contributing to the performance of asphalt pavements in Maine.

In 2015, MaineDOT began using the Hamburg wheel-tracking test (HWTT) to evaluate their asphalt mixtures to immediately address durability and raveling issues. The premature pavement failures across the state were the impetus behind the use of HWTT as a performance-related test to evaluate the rutting and moisture susceptibility of asphalt mixtures. Performance testing data were used to identify measures that can be taken to extend the service life of asphalt mixtures used by MaineDOT. This effort led to changes in their specifications, including the addition of hydrated lime to some of their mixtures along with the use of HWTT as part of an asphalt mixture design and verification process for certain projects (based on roadway classification).

There is a strong belief within MaineDOT for the need to move beyond volumetric properties for asphalt mixture designs and acceptance through the use of performance tests. Though, a staged approach for the implementation that takes into consideration the efficiency and level of sophistication of the performance test is needed to assure a comfortable transition from volumetric to performance tests. Thus, in parallel to the work with AMPT performance testing, MaineDOT initiated in 2019 a new effort to evaluate the cracking and rutting resistance of asphalt mixtures using the indirect tensile cracking test (formerly known as IDEAL-CT) and the

IDEAL-RT, respectively. Both of these tests are similar to Marshall stability test and can be easier and simpler to implement as part of a routine asphalt mixture design and to use in their QA program (process control and quality control, agency acceptance, independent assurance, etc.).

The predictive BMD based on the direct tension cyclic fatigue and SSR using the AMPT involves the prediction of pavement performance over time. This helps MaineDOT early on in making informed decisions on the type and quality of their asphalt mixtures while eluding the need to construct and wait for several in-service years to confirm field pavement performance. It can help justifying any added cost associated with the use of new materials with their asphalt mixtures such as the case with polymer-modified asphalt binders. The AMPT performance tests are also used as a reference for comparison and better selection of index-based performance tests. However, the complexity and time involved in specimen fabrication and in conducting the direct tension cyclic fatigue and SSR tests make them less likely to be part of project acceptance.

The current MaineDOT QA specification (i.e., percent within limits—PWL) aims at ensuring a consistent asphalt mixture during production, but does not necessarily target a desired performance level. Thus, MaineDOT is motivated by the need for reliable index-based performance tests with acceptable relation to field pavement performance to ensure: asphalt binder quality and quantity, proper durability/cracking and rutting resistance, target asphalt mixture performance, and conformance to QA specifications (get what MaineDOT paid for). The performance tests are also helping MaineDOT in the evaluation of specialty asphalt mixtures such as asphalt rubber gap-graded mixtures and other innovations.

BMD APPROACH

While MaineDOT has implemented the use of HWTT, it is still working on the implementation of a complete BMD approach for designing asphalt mixtures. MaineDOT is currently in the process of evaluating durability/cracking and rutting performance tests for routine use in a BMD process and acceptance. This effort in the state is being led by MaineDOT and has stimulated a few paving contractors and an asphalt binder supplier to acquire an indirect tensile cracking test equipment. They are all starting the development of a baseline database of the cracking tolerance index parameter for their typically produced asphalt mixtures.

MaineDOT envisions that a tiered system from Approach A through Approach C is most likely to be implemented in order to build good understanding of the performance tests with industry partners. This involves pilot projects for a number of years; thus, allowing enough time for contractors to acquire the necessary performance test equipment and for MaineDOT to build confidence in the shift from volumetric to performance-related asphalt mixture design. Over time confidence in the performance test methods and their correlation to field pavement performance enables eventual shift to Approach D. The following summarizes the currently implemented MaineDOT's asphalt mixture design process using the HWTT. Figure 1 shows a flowchart of the overall asphalt mixture design.

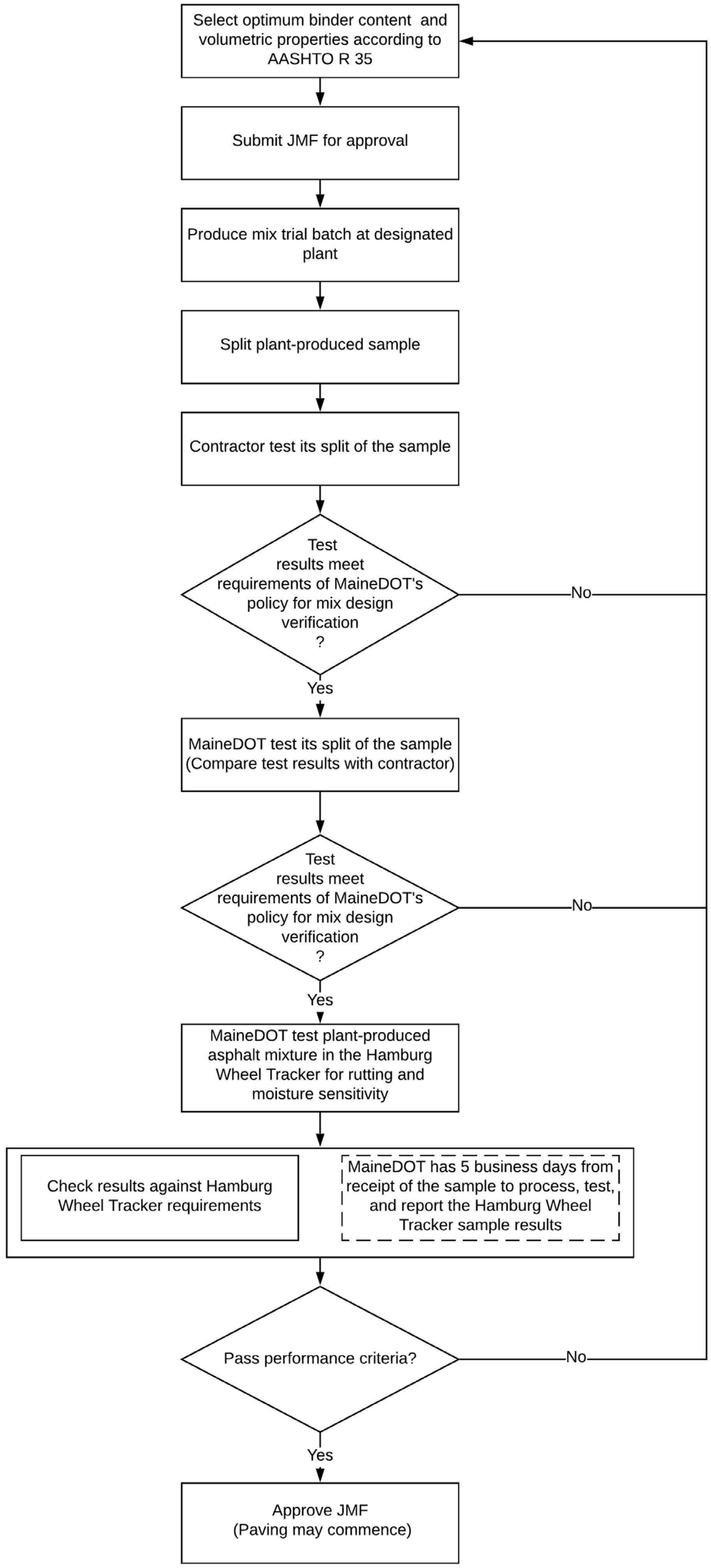

Figure 1. Chart. Overview of MaineDOT asphalt mixture design approach using HWTT.

According to Section 401 – HOT MIX ASPHALT PAVEMENT (HMA Hamburg Wheel Tracker Specification) of the SPECIAL PROVISION DIVISION 400 PAVEMENTS, the contractor designs the asphalt mixture to be supplied in accordance with the process described in AASHTO R 35 and the volumetric criteria in table 1. The design, verification, quality control, and acceptance tests for this mixture are performed at 65 gyrations. The contractor then submits a job mix formula (JMF) for MaineDOT's approval.

Table 1. Volumetric Design Criteria.

Design ESAL's (millions)	Required Density (% of maximum theoretical specific gravity)			VMA (Minimum Percent)					VFB (Minimum %)	Fines to Effective Binder Ratio
	$N_{initial}$	N_{design}	N_{max}	NMAS (mm)						
				25	19	12.5	9.5	4.75		
<0.3	≤91.5	96.0	≤98.0	13.0	14.0	15.0	16.0	16.0	70–80	0.6–1.2
0.3 to <3	≤90.5	96.0	≤98.0	13.0	14.0	15.0	16.0	16.0	65–80	0.6–1.2
3 to <10	≤89.0	96.0	≤98.0	13.0	14.0	15.0	16.0	16.0	65–80*	0.6–1.2
10 to <30	≤89.0	96.0	≤98.0	13.0	14.0	15.0	16.0	16.0	65–80*	0.6–1.2
≥30	≤89.0	96.0	≤98.0	13.0	14.0	15.0	16.0	16.0	65–80*	0.6–1.2

*For 9.5 mm NMAS mixtures, the maximum VFB is 82.
*For 4.75 mm NMAS mixtures, the maximum VFB is 84.

In comparison to AASHTO M 323 "Standard Specification for Superpave Volumetric Mix Design," MaineDOT implemented the following key modifications to their volumetric design criteria (table 1):

- Increased the voids in mineral aggregate (VMA) requirement by 1% for asphalt mixtures with a nominal maximum aggregate size (NMAS) between 9.5 and 25 mm.
- Increased, in particular, the upper limit requirement for the voids filled with binder (VFB).
- Decreased the number of gyrations for design and acceptance of asphalt mixtures to 65 gyrations.

The above changes to AASHTO M 323 aimed at increasing the durability and cracking resistance of the asphalt mixture by letting more asphalt binder into the mixture (the higher the VMA, the higher the asphalt binder content for a given air void level).

The JMF is approved in accordance with the MaineDOT HMA Policies and Procedures for HMA Sampling and Testing Manual. The contractor shall submit a new JMF for approval each time a change in material source or material properties is proposed. Mix designs are submitted and approved on a system-wide basis where they can be used on multiple projects from year to year (assuming acceptable Acceptance results).

Before the start of paving, the contractor provides MaineDOT with a plant-produced asphalt mixture. The contractor first tests its split of the sample and determine if the results meet the requirements of MaineDOT's policy for mix design verification. If acceptable, MaineDOT will then test its split of the sample and the results of the two split samples will be compared. If the asphalt mixture meets the requirements for mix design verification, the JMF is approved.

For those projects requiring asphalt mixtures to meet rutting and stripping tests, the mixture will then be tested for rutting and moisture sensitivity in the Hamburg wheel tracker (HWT) according to AASHTO T 324, "Hamburg Wheel-Track Testing of Hot Mix Asphalt (HMA)" and the MaineDOT's policy for modifications to AASHTO T 324 (dated March 1, 2019). The sample will be required to meet the applicable requirements of table 2 for JMF approval depending on the asphalt binder performance grade (PG).

Table 2. HWTT Requirements for Asphalt Mixture Design Verification.

Specified PG	Test Temperature (°C)	Maximum Rut Depth (mm)	Minimum Number of Passes	Minimum Allowable Stripping Inflection Point (SIP)
PG64-28	45	12.5	20,000	15,000
PG64E-28	48	12.5	20,000	15,000
PG70E-28	50	12.5	20,000	15,000

SELECTION OF PERFORMANCE TESTS

Table 3 summarizes the asphalt mixture performance tests currently used or being evaluated by MaineDOT for possible use into future implementation of a BMD approach. A final decision has not been made, but these tests are the ones currently under evaluation. MaineDOT was introduced to HWTT and direct tension cyclic fatigue tests during their involvement with the AASHTO Strategic Highway Research Program 2 (SHRP2) Performance Specifications for Rapid Renewal (R07). MaineDOT then selected the HWT device after reviewing related specifications and procedures for other SHAs (having a standard test method by AASHTO further helped MaineDOT in the selection process). The HWTT was selected to assist MaineDOT in the raveling research, which focused on the premature failure of asphalt pavements in Maine due to raveling or loss of material in the wheel paths.

MaineDOT considers performance tests (direct tension cyclic fatigue and SSR) run on the AMPT as tools for in-depth evaluation of asphalt mixtures. However, there is still a need to relate performance test results from simpler and quicker tests for implementation to those run on the AMPT. The direct tension cyclic fatigue will not be part of project acceptance and cannot be used for day-to-day acceptance or process control. Most of the causes of pavement failures are a result of changes that happen during production. No matter what test is selected, the performance test will be part of production testing. A likely result of this will be the awareness that contractors will need to improve their process control. Additionally, contractors will need results from a performance test promptly such that they can make decisions on production based on the results.

Thus, the indirect tensile cracking test was selected as an alternative to the direct tension cyclic fatigue test recognizing the time and complexity limitations of the direct tension cyclic fatigue test and the necessary sample preparation. This test was selected after reviewing literature on performance tests from other SHAs and research centers. Preliminary testing was first conducted by MaineDOT to verify the indirect tensile cracking test before moving forward with a comprehensive experimental plan to test asphalt mixtures. Results can be obtained extremely quickly from the indirect tensile cracking test. The similarity between the sample preparation of the indirect tensile cracking test and HWTT make the performance test selection and implementation advantageous. Samples can be prepared in an assembly-line type manner.

Preparing samples for the direct tension cyclic fatigue test is a different matter. In terms of implementation by the contractors, the indirect tensile cracking test was much easier for them to understand than the HWTT, and contractors have much of the equipment readily available.

Test results from the AMPT are being used to create a database of common materials. The database will potentially be used as a Level 2 pavement thickness design within PavementME.

Table 3. Summary of Performance Tests Considered by MaineDOT for BMD.

Elements	Stability/Rutting	Durability/Cracking	Moisture Damage/Stripping
Test Name	Hamburg Wheel-Tracking Test (HWTT)	Indirect Tensile Cracking	Hamburg Wheel-Tracking Test (HWTT)
Test Method	AASHTO T 324-17	ASTM D8225-19	AASHTO T 324-17
Test Criteria	Refer to table 2.	–	Refer to table 2.
Test Implemented in Asphalt Mixture Design	Yes.	No.	Yes.
Aging Protocol	Lab-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C). Plant-produced mixtures: Reheated at compaction temperature.	Lab-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C) Plant-produced mixtures: Reheated at compaction temperature.	Lab-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C) Plant-produced mixtures: Reheated at compaction temperature.
Notes/Comments	MaineDOT policy HMA Hamburg Wheel Tracker Testing, March 1, 2019. Policy identifies the MaineDOT modifications to AASHTO T 324. It also provides details on the standardized reporting for results. MaineDOT is investigating the use of AMPT SSR AASHTO TP 134 for high profile projects. MaineDOT is also investigating the use of ideal shear rutting test (IDEAL-RT) for acceptance.	MaineDOT is investigating this test method along with AMPT direct tension cyclic fatigue and small specimen dynamic modulus (AASHTO TP 107, AASHTO TP 132, and AASHTO TP 133) for high profile projects.	MaineDOT policy HMA Hamburg Wheel Tracker Testing, March 1, 2019. Policy identifies the MaineDOT modifications to AASHTO T 324. It also provides details on the standardized reporting for results.

– indicates not available.

The top three factors for MaineDOT in selecting a performance test are: repeatability/reproducibility, field validation, and material sensitivity. For MaineDOT, having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications. Field validation and correlation of performance test results with measured field performance data was one of MaineDOT's motivations for implementation of performance tests. The sensitivity of a performance test result to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), air voids, and aging is also as important. Contractors need to be able to make informed decisions on what changes can be made to the asphalt mixture composition in order to improve performance and meet applicable specification limits. Other important factors are sample preparation, equipment cost, applicability to lab-molded specimens and field cores, etc.

In 2015, the HWTT was used to evaluate and improve the durability and performance of asphalt mixture JMFs used on MaineDOT projects statewide. This led to the implementation of hydrated lime usage on select pilot projects, polymer-modified asphalt binders in approximately 50% of the projects in the state, expanded requirements for use of liquid anti-strip additives, and a consolidated asphalt mixture design performed at 65 gyrations.

PERFORMANCE TESTS DEVELOPMENT TO IMPLEMENTATION

The following section summarizes MaineDOT's experience with performance test implementation in terms of the nine essential steps identified in NCHRP Project 20-07/Task 406.

Step 1. Draft test method and prototype equipment.

Having an existing standard test method supported efficient implementation of the HWTT for asphalt mixtures in Maine. However, the lack of some specific details in the standard procedure; in particular those related to the calculation of the index parameters (e.g. SIP), created challenges during the implementation process that had to be addressed. For instance, different HWT device manufacturers had different analysis methodologies that led to differences in some of the calculated test parameters (MaineDOT has HWT devices from two different manufacturers). This forced MaineDOT to develop its own Microsoft Excel spreadsheet for data analysis and calculation so test results are all analyzed following the same methodology. Upon request by contractors, MaineDOT also developed a written policy for HWTT. The policy identifies the MaineDOT modifications to AASHTO T 324 and provides details on the standardized reporting to be used by MaineDOT and contractors for results of HWTT. A similar challenge may be faced by MaineDOT with the indirect tensile cracking test.

MaineDOT realizes the great need for having more robust standard test methods to avoid any test result differences between different equipment manufacturers. This includes having procedures with clear and specific descriptions and details on:

- Associated calculation and analysis methods and techniques.
- Standardized reporting of test results and parameters.
- Database attributes for the stored raw/primary test data.

MaineDOT can highly benefit from guidance on proper procedures for storing raw data attributes. Putting primary test data into an appropriate database, enables the raw data to become accessible in the future for further processing and analysis in other different ways. For instance, if a new index parameter is developed in the future, the raw test data can be available to calculate the new value; thus taking advantage of previously completed efforts and most importantly of any associated field pavement performance collected over the years for the tested asphalt mixtures.

Step 2. Sensitivity to materials and relationship to other laboratory properties.

MaineDOT conducted extensive testing of asphalt mixtures from the state using the HWTT as part of their studies on asphalt durability and antistrip treatments. However, a comprehensive study to assess the influence of changes in volumetric and other properties and their relationship to the performance of the asphalt mixtures is not practical; because their design method is based on plant-produced asphalt mixtures. Nevertheless, the HWTT helped MaineDOT to address the impact of hydrated lime and polymer-modified asphalt binders on the durability and moisture damage resistance of asphalt mixtures. While improvements in durability and moisture damage were observed, this was not true across all evaluated asphalt mixtures. Those mixtures that were already good in the HWTT showed little or no improvements with the addition of hydrated lime and polymer-modified asphalt binder. Improvements in test results from the HWTT when using hydrated lime in the laboratory were not always observed in the field due to the methods hydrated lime was added at the plant. In general, the performance testing showed more benefits for the asphalt mixtures with 9.5 mm than with 12.5 mm NMAS.

To supplement the benefits observed with the HWTT, additional questions were raised related to possible improvements in the resistance of the asphalt mixtures to cracking. Thus, MaineDOT made use of performance testing (e.g., indirect tensile cracking test) as part of a study initiated in 2019 to help address and identify potential added benefits for antistripping treatments and polymer-modified asphalt binders. This new effort is generating additional data for MaineDOT in a step forward towards the full implementation of a BMD approach in the state.

MaineDOT expressed the need as a SHA for having established mechanisms for seeking desired outside support with the analysis of performance test results. It is imperative to confirm the validity of any data analysis before making any conclusions on the observed results and trends.

Step 3. Preliminary field performance relationship.

MaineDOT based its selection of performance tests criteria on existing research studies and specifications from other SHAs. A preliminary relationship to field performance was confirmed for the HWTT with a forensic study of failed pavements and a regional research project using Maine's asphalt mixtures. MaineDOT will continue to build-up its database of performance test results on asphalt mixtures and make use of it for establishing a state-specific relationship between test results and field performance in Maine.

Step 4. Ruggedness experiment.

MaineDOT did not conduct or participate in any ruggedness testing yet. It has plans to participate in AMPT ruggedness testing for direct tension cyclic fatigue and SSR although they have not been updated on the progress of the project and their potential involvement. The deviation from an initial implementation timeline and the delay in the conduct of a ruggedness experiment can negatively impact the overall process towards full implementation of performance testing.

Step 5. Commercial equipment specification and pooled fund purchasing.

MaineDOT invested in new equipment and accessories in order to undertake performance testing including one AMPT, two HWT devices, and two Indirect Tensile Cracking devices. This involved additional resources to create new areas in the laboratories to accommodate equipment.

Step 6. Interlaboratory study (ILS) to establish precision and bias information.

MaineDOT conducted two consecutive round robins with industry partners prior to the development and implementation of the policy on HWTT. The overall purpose of this effort was to gain trust and comfort with the HWTT. The second round robin showed improvements over the first round robin, leading to prescribed procedures for sample preparation, HWT set-up, and reporting (including calculation method). In the first round robin, the lack of experience in fabricating and handling (e.g., conditioning) test specimens resulted in differences between participants.

Step 7. Robust validation of the test to set criteria for specifications.

The HWTT performance criteria were based upon specifications from other SHAs (especially neighboring states), and revised based on comparison of test results to historical field pavement performance. In a continuous effort to advance implementation, MaineDOT supported external studies to evaluate the HWTT and to validate or establish new performance criteria using asphalt mixtures from the state. The current HWTT performance criteria need to be subjected to a robust validation and be calibrated as needed to local climate and materials conditions.

A study completed by University of New Hampshire and funded by the New England Transportation Consortium (NETC) evaluated the ability of multiple asphalt mixture performance tests to identify good and poor performing mixtures with respect to moisture-induced damage. The study included plant-produced asphalt mixtures from several New England states, including Maine, with established good and poor in-situ moisture performance. It was concluded that the HWTT is the most effective and practical test method for routine usage during asphalt mixture design. The test reliably identified asphalt mixtures prone to experiencing significant amounts of moisture-induced damage. This study confirmed MaineDOT's use of the HWTT such that no recommendations were made for changes to the existing MaineDOT requirements (i.e., performance test criteria).

The HWTT is used on a number of select projects carefully chosen out of the list of candidate projects identified for the next construction season. Factors considered in this selection process are asphalt mixture intended application and serviceability (e.g., new, major rehabilitation), road classification, and traffic level. The MaineDOT's HWTT requirements for asphalt mixture design verification and acceptance (table 2) is a function of the traffic level and priority; inferred from the three different PGs of the asphalt binder. Furthermore, the testing temperature is adjusted based on the required minimum PG of the asphalt binder.

When selecting a cracking test, a big part of implementation will be the ability to have achievable and realistic specifications that are tied to performance. Thus, having the ability to acquire external support to provide proper technical inputs and feedback on the process for establishing and validating performance test criteria for specifications is valuable.

Step 8. Training and certification.

Trained and dedicated technicians on the procedures and analysis of test results were needed. This initially involved a strong support from the upper management by approving a request to hire dedicated staff and create a new area for hosting the testing and fabrication equipment. For instance, resources were allocated to convert a stairwell into a room to house the AMPT equipment and the janitor's closet into a space for coring and sawing specimens. No Special accommodations were necessary for the indirect tensile cracking test that is being run using an already existing loading frame in the laboratory. When additional space was needed, a decision was made to outsource the testing of Portland cement, and repurpose that space for fabrication of compacted specimens for performance testing. A separate area in the laboratory was then created for education and training on the use of various performance tests. The "trial and error" testing was conducted during the construction off-season.

The current staffing level is considered proficient and adequate for the current plan because the indirect tensile cracking test is simple and quick to complete. On the other hand, sample fabrication is the bottleneck when it comes to any performance test and has the biggest impact on resources. An additional gyratory compactor was procured in order to increase productivity of fabrication processes for performance testing. Achieving the target air void level of the compacted specimens is the most challenging task during production and construction. Technicians needed to develop proficiency at fabricating specimens to target constant air voids with limited volumetric information. However, through practice, MaineDOT staff learned and established a process for facilitating sample preparation and reducing the number of iterations needed to produce acceptable specimens. A Microsoft Excel spreadsheet was created to predict the sample weight to get target air voids. It is linear and a function of being a fine or coarse mix. The similarities in size and shape of the specimens for the HWTT and indirect tensile cracking test simplified the process and made it convenient. All that was needed was few extra boxes of plant-produced asphalt mixtures.

Currently state laboratories are AASHTO re:source accredited. Contractor laboratories are not required by MaineDOT to be accredited and there is no plan to implement accredited laboratories for the use of performance tests. The implementation of a performance test for acceptance is a large effort involving significant training. It is envisioned that at one point a certified asphalt mixture designer is needed for a BMD approach, most likely through the regional certification body for the northeast, Northeast Transportation Training and Certification Program (NETTCP). Collaboration between the SHA and regional or national organizations and groups is needed to develop and establish such a certification program.

Step 9. Implementation into engineering practice.

MaineDOT is working with industry partners to implement new specifications through a series of pilot projects using phased-in approach. Pilot projects help both contractors and MaineDOT to become more familiar with the performance test and how results impact the design and acceptance of asphalt mixtures. MaineDOT noted that the timeline for full implementation (steps 1 through 9) is critical and an SHA should avoid delays and deviations from the set initial timeline.

MaineDOT noted the time difference related to specimen fabrication of different performance tests and the importance of this aspect during the implementation process into engineering practice. For instance, if mass-production of test specimens is maintained, at least a dozen per day or 60 per week of asphalt mixture tests in the indirect tensile cracking test can be completed. Essentially, the number of tests that can be completed per day is mainly limited by oven space for aging of the loose asphalt mixture and the water bath/conditioning chamber space for the conditioning of specimens prior to testing. In the case of the HWTT, two sets of tests can be completed per day or 10 per week. With some other more complex performance tests (e.g., direct tension cyclic fatigue using the AMPT), it may take up to one week to fabricate and test for one single asphalt mixture.

IMPLEMENTATION OF PERFORMANCE TESTS ON PROJECTS

MaineDOT led and invested significantly in the process during the implementation effort of the HWTT of asphalt mixtures in the state. At first, few contractors were interested but there was trepidation due to contractors not being experienced with performance testing, having marginal aggregates and expressed concerns with failing test requirements, etc. It took time, dialogue, education, and partnering to get the HWTT implemented on higher profile projects. The genesis of this effort came from the industry preference to have a performance test(s) that can identify asphalt mixtures that needed moisture-damage mitigation the most. This came after MaineDOT was considering to mandate the use of hydrated lime in all of its asphalt mixtures used in the state.

MaineDOT partnered with contractors and provided them with “informational testing” from the HWT on their different asphalt mixtures to gain knowledge with their mixtures’ performance. Unused dispute splits of acceptance samples were used to fabricate and test specimens for the most commonly used asphalt mixture designs in the state for a number of years. This gave the industry an opportunity to try different asphalt mixtures and establish an understanding of passing and failing asphalt mixtures in the HWTT. A similar process is planned for the indirect tensile cracking test effort. However, this test is anticipated to be better received by contractors because of its simplicity and contractors’ ability and readiness to run the test.

The HWTT is currently used as a go/no-go design and acceptance criteria. During production, MaineDOT requires the contractor to sample and test asphalt mixtures in the HWT as quality control according to AASHTO T324 at a frequency of 1 per 4,000 ton and at least once per acceptance lot. MaineDOT also samples and tests the asphalt mixture during production to verify compliance with the HWT requirements (table 2). If a sample fails to meet the criteria in table 2, the contractor has to provide a corrective action plan to bring the mixture back into compliance. Requested changes are to be first approved by MaineDOT. Mixtures that have consistent issues with failing HWTT results can have their approval revoked as a result. The test results are currently not tied to a pay factor for asphalt pavements. Thus, the time to test and report back the results of sampled asphalt mixtures during production to the contractor have not usually been an issue (1 to 2 weeks typical turnaround time). It is also possible for a contractor to have failing HWTT results but still get a bonus for delivering a consistent asphalt mixtures in relation to volumetric and other properties.

The HWTT was initially used on interstate mill and fill projects only. Then this was expanded to high investment, then to other higher-profile projects and reconstruction projects (significant investments). Use of the specification is tied to the priority level of the corridor on which the project is located, with it being used on priority levels 1 and 2 (out of 1 to 4). Tonnage is also a consideration (more than 4,000 tons) in the project selection and asphalt mixtures are mainly 12.5 mm NMAS.

MaineDOT found that having a technician responsible for sample preparation and fabrication and another for performance testing is more effective and practical. The quantity of materials needed to produce test specimens and the effort to reach target air void level vary between the different performance tests. In some cases, more iterations are needed to produce test specimens that are in compliance with air void limits.

By implementing proper performance tests for durability/cracking and rutting within a BMD approach, the hope is to be able to loosen up some volumetric property requirements; thus allowing the contractors to be creative and see the benefits of the tests. However, a key question contractors want to have answered is what corrective changes to make in order to bring the asphalt mixture back into compliance. MaineDOT is partnering with contractors on this aspect; though, for performance testing to be effective, better process control is going to be needed.

After implementing the HWTT requirements for asphalt mixtures, around half of the asphalt mixtures historically submitted and approved by MaineDOT had to be modified. In general, a reduction in the use of natural sands and an increase in the use of polymer-modified asphalt binders was observed. No substantial difference in asphalt binder content or reclaimed asphalt pavement (RAP) content was observed.

OVERALL BENEFITS

In 2010, the significant raveling experienced in asphalt overlays was estimated to cost MaineDOT about $15 million in one year. Overall with the implementation of the HWTT in Maine, fewer cases of premature failures were observed, leading to significant cost savings for MaineDOT. If only 50% of the asphalt mixtures throughout the state exhibited improved raveling and durability performance, cost savings can be in the order of $7.5 million per year.

Though the durability improved for a large number of the asphalt mixtures, some poor field performing mixtures still passed the HWTT criteria. It is worth mentioning that many of the projects are thin asphalt overlays (1.5 inches or less) and only few projects are full reconstruction. Larger benefits in implementing the HWTT were observed on the reconstruction projects.

FUTURE DIRECTION

MaineDOT's future directions are summarized as follows:

- Develop and execute a plan to evaluate and select performance tests and their related index parameters for implementation.
- Conduct round robin studies with other SHAs and with industry partners.

- Establish performance test limits based on ties between the test results and field pavement performance. Consider traffic and environment as part of the test criteria.
- Conduct additional pilot projects to facilitate implementation after making decision on performance tests to be used.
- Work with NETTCP to develop a BMD certification course.

POSITIVE PRACTICES, LESSONS LEARNED, AND CHALLENGES

The following is a list of positive practices, some lessons learned, and challenges from MaineDOT that can help facilitate the implementation of a performance test into practice. Positive practices are those successful efforts that were used by MaineDOT that could also be considered by other SHAs. Lessons learned are those efforts that, if MaineDOT had it to do over again, they would definitely reconsider. Challenges are those efforts that MaineDOT is still in the process of addressing.

Positive Practices

- MaineDOT had an immediate need to address durability and raveling issues which was their motivation for implementation of the HWTT. Their QA specification (i.e., PWL) aimed at ensuring the consistency of the asphalt mixture during production and did not necessarily target a desired performance level. Overall, the implementation of the HWTT resulted in fewer premature failures. Though the durability improved for a large number of asphalt mixtures, there were still some poor performing projects. Most causes of pavement failures were a result of changes that happened during production. The HWTT test was included as part of production testing.
- Agency-industry partnership is important for a successful and smooth implementation of performance tests as part of asphalt mixture design and acceptance. This involves good communication and continuous dialogue with the industry, knowledge transfer, and necessary education and training.
    - While MaineDOT's experience with this process was time consuming and required their lead, it was very important in moving forward with implementation of the HWTT.
    - Communicating with contractors the impact of new specifications on the design and acceptance of their asphalt mixtures is key to facilitating implementation.
    - MaineDOT also conducted and shared test information with contractors on their different asphalt mixtures to gain knowledge with performance tests.
- Implementation of performance testing required allocation of additional resources from MaineDOT.
    - Proper planning in advance of laboratory space need for sample preparation, testing, and training on the new performance tests is necessary.
    - Planning for having dedicated skilled technicians is essential and involves the approval and support of the upper management.
    - Having technicians dedicated for sample preparation and fabrication and others for performance testing helps improving efficiency.
- MaineDOT conducted two consecutive round robins with industry partners to gain trust and comfort with the HWTT. After the first round robin, procedural changes relating to

sample preparation, HWT set-up, and reporting were made. The results from the second round robin showed improvements.

- The HWTT performance criteria were based upon specifications from other SHAs (especially neighboring state), and revised based on comparison of test results to historical field pavement performance.
- Project selection guidelines were very beneficial in using Maine DOT's resources most effectively. These guidelines focused on interstate and high investment projects, then to other higher-profile projects and reconstruction projects (significant investments). Tonnage was also a consideration (more than 4,000 tons).
- MaineDOT implemented performance tests one at a time. The HWTT was implemented initially to address an immediate need with durability and raveling. Following that implementation, the efforts to implement a cracking test were initiated.
- Considerations should be given to the size and shape of test specimens when attempting to implement multiple performance tests. Having similar test specimens for the different candidate performance tests helps in accelerating the learning curve, testing process, and the turnaround time.
- Conducting testing and establishing a large database of test results on typical asphalt mixtures used in the state helps in understanding the performance of the mixtures and establishing a comfortable transition from volumetric to performance tests.
- MaineDOT implemented a consolidated asphalt mixture design performed at 65 gyrations along with modifications to their volumetric design criteria for increasing the VMA and VFB requirements.
- MaineDOT envisions a certification program for an asphalt mixture designer for BMD. This will be done in collaboration between SHA and regional or national organizations.

Lessons Learned

- Conducting thorough and in-depth review of literature, peer exchanges, and dialogues with professionals/researchers is a critical first step in the process for selecting candidate performance tests. Thus, developing a good understanding of; the performance test, the background test development information, the test use and application, the performance test criteria, and the intent and significance of the test results. After implementation of the HWTT, it was recognized that this was an area for improvement. These techniques have been followed when using the indirect tensile cracking test.

Challenges

- Having robust standard test methods with clear and specific descriptions and details on:
    - The calculation and analysis methods and techniques.
    - The standardized reporting of test results and parameters.
    - The database attributes for the stored raw/primary test data.

  This can eliminate the need to overcome some challenges related to having equipment from different manufacturers. Efforts have been made in this area, but there is still work to be done.

- Sample preparation and specimen fabrication were found critical by MaineDOT during the implementation process of a performance test. The complexity of sample preparation (i.e., involves multiple coring, cutting, or notching activities) is on the critical path for time to complete the test. The ability to reach target air void level on reheated plant-mixed lab-compacted specimens can delay testing. Thus, having technicians with proper expertise along with established procedures for reaching target air voids was needed by MaineDOT.
    - For simple specimens, it commonly takes qualified technicians two attempts, but can be done in one or three attempts using a Microsoft Excel spreadsheet MaineDOT created. This was further expedited with the familiarity of the technicians with sample geometry (e.g., HWTT and indirect tensile cracking tests).
    - For tests requiring coring multiple test specimens from a larger compacted gyratory sample, it is extremely difficult to always get all specimens within air voids tolerance.
- Having some guidelines on what changes can be made during production to get an asphalt mixture back in compliance by passing performance test criteria is of great need. This information will accelerate the implementation of any performance test as part of acceptance of asphalt mixtures.
- Having someone knowledgeable in database and information management systems is important for properly storing and accessing performance tests data. This information would be valuable if a new index parameter is developed in the future; the primary/raw test data would be available to calculate the new value. Guidance from experts on key data parameters for each test would be helpful to address these concerns. MaineDOT is currently using a Microsoft Access database for managing and storing test results and associated information.

No matter what test is selected, MaineDOT desires that the performance test be part of production testing. A likely result of this will be the awareness that contractors will need to improve their process control. Additionally, contractors will need results from a performance test promptly such that they can make decisions on production based on the results. At this time, it is difficult for MaineDOT to perceive how some of the performance test methods used in BMD can be implemented for acceptance purposes. There may be a need to either move towards simpler performance tests or to use BMD as strictly an asphalt mixture design approval and verification tool. Quality during production would rely on using traditional methods (although with a focus on strict process control protocols to minimize production variability). Once contractors develop an acceptable level of comfort with performance tests, performance-volumetric relationships could then be possibly established through performance testing of asphalt mixtures as part of the mix design stage. Nonetheless, using a simple index-based performance test along with improved process control to minimize variability from design may offer a better approach for assuring that BMD properties are met during production.

RESEARCH OPPORTUNITIES

MaineDOT suggests the following research topics:

- What changes can be made to the asphalt mixture composition, components, and proportions to get acceptable results in performance tests (e.g., increase in asphalt binder content, decrease in fine contents, use of additives, etc.). Contractors can then make cost-benefit analysis decisions based on this information. There was a steep learning curve for Superpave volumetric mix design and it will be similar for performance testing. Findings from the study can accelerate the learning curve and facilitate the implementation of performance testing.
- Procedures and guidelines on how to implement performance testing of asphalt mixtures in the acceptance process. The study needs to look into a practical approach that takes into consideration testing turnaround time (including sample fabrication and consideration of many projects occurring simultaneously in the paving season), repeatability and reproducibility, material sensitivity, and associated risks.

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