

Positive Practices, Lessons Learned, and Challenges When Implementing Balanced Design of Asphalt Mixtures: Site Visits



Image: University of Nevada, Reno

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ABSTRACT

Virtual site visits and interviews of seven key State Departments of Transportation (DOTs), along with material producers, consultants and paving contractors that serviced the agencies were conducted to learn more regarding the details of Balanced Mix Design (BMD) and performance tests implementation efforts. Successful practices documented from these virtual site visits were collected and synthesized into an overall process of implementing BMD as part of mix design approval and quality assurance (QA). This process comprises eight major tasks that are meant to present and summarize the activities that a State DOT may need to undertake to implement a BMD program depending on its organizational structure, staffing level, workspace, annual asphalt tonnage, as well as industry experiences and practices. Examples of positive practices, lessons learned, and challenges from States for the various tasks are presented. A list of research and deployment topics identified during the virtual site visits are also summarized.

Key Words: balanced mix design, pavement performance, cracking, durability, rutting, implementation, specifications.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADI	Asphalt District Inspector
ADT	average daily traffic
AJMF	adjusted JMF
ALF	Accelerated Loading Facility
AMPT	Asphalt Mixture Performance Tester
APA	Asphalt Pavement Analyzer
APT	accelerated pavement testing
AQCs	acceptance quality characteristics
ASTM	American Society for Testing and Materials
BDWSC	Bridge Deck Waterproofing Surface Course
BM	base asphalt mixture
BMD	Balanced Mix Design
BRIC	Binder Rich Intermediate Course
BRBC	Binder Rich Base Course
CAIT	Center for Advanced Infrastructure and Transportation
Caltrans	California DOT
CAM	crack attenuating mixture
CBM	Central Bureau of Materials
COV	coefficient of variation
CTIS	Center for Transportation Infrastructure Systems
CTR	Center for Transportation Research
DOT	Department of Transportation
ESAL	equivalent single axle load
FBF	Flexural Bending Fatigue
FHWA	Federal Highway Administration
FI	flexibility index
Gmm	theoretical maximum specific gravity
GPC	gel permeation chromatography
HMAC	Hot Mix Asphalt Center
HPTO	High-Performance Thin Overlay
HRAP	Hot Mix Asphalt High RAP
HVS	Heavy Vehicle Simulator
HWTT	Hamburg Wheel-Tracking Test
IAC	Interagency Cooperation Contract
IDEAL-CT	ideal cracking tolerance
IDEAL-RT	ideal shear rutting
I-FIT	Illinois Flexibility Index Test
IAPA	Illinois Asphalt Pavement Association
ICT	Illinois Center for Transportation
IDOT	Illinois DOT
IDT	indirect tensile

ILS	interlaboratory study
IM	intermediate asphalt mixture
JMF	job mix formula
LDOTD	Louisiana DOT and Development
LLAP	long-life asphalt pavement
LLPRS	Long Life Pavement Rehabilitation Strategies
LPLC	laboratory-produced laboratory-compacted
LTPP	Long-Term Pavement Performance
LTRC	Louisiana Transportation Research Center
MaineDOT	Maine DOT
ME	mechanistic-empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
METS	Materials Engineering and Testing Services
MOT	Ministry of Transportation
MPL	material producer list
MTD	Materials and Tests Division
NCHRP	National Cooperative Highway Research Program
NDT	non-destructive testing
NETC	New England Transportation Consortium
NETTCP	Northeast Transportation Training and Certification Program
NJDOT	New Jersey DOT
NMAS	nominal maximum aggregate size
OBC	optimum binder content
OGFC	open graded friction course
OT	Overlay Tester
PAV	pressure aging vessel
PCC	portland cement concrete
PFC	permeable friction course
PG	performance grade
PMS	pavement management system
PPLC	plant-produced laboratory-compacted
PRS	performance-related specifications
PSP	Pavement Support Program
PWL	percent within limits
QA	quality assurance
QC	quality control
RA	recycling agent
RAP	reclaimed asphalt pavement
RAS	reclaimed asphalt shingles
RBR	reclaimed binder ratio
RLT	repeated load triaxial
ROI	return on investment
RSP	Reference Sample Program
RSST	repeated simple shear test
RWC	rolling wheel compaction
SB	styrene-butadiene

SBR	SB rubber
SBS	SB-styrene
SCB	semi-circular bend
SGC	Superpave gyratory-compacted
SHRP	Strategic Highway Research Program
SIAD	Statewide Independent Assurance Database
SIP	stripping inflection point
SM	surface asphalt mixture
SMA	stone matrix asphalt
SP&R	State Planning and Research
SPS	Special Pavement Study
SST	Superpave Shear Tester
SSR	stress sweep rutting
STIC	State Transportation Innovation Council
TBFC	thin bonded friction courses
TFHRC	Turner-Fairbank Highway Research Center
TOM	thin overlay mixtures
TS	tensile strength
TSR	tensile strength ratio
TTI	Texas A&M Transportation Institute
TXAPA	Texas Asphalt Pavement Association
TxDOT	Texas DOT
U.S.	United States
UCPRC	University of California Pavement Research Center
UIUC	University of Illinois at Urbana-Champaign
UTA	University of Texas at Austin
UTEP	University of Texas at El Paso
VAA	Virginia Asphalt Association
VDOT	Virginia DOT
VECAT	Virginia Education Center for Asphalt Technology
VFA	voids filled with asphalt
VMA	voids in mineral aggregate
VTRC	Virginia Transportation Research Council
WMA	warm mix asphalt

Symbols

J_c	critical strain energy release rate
N_{design}	design number of gyrations
$N_{initial}$	initial number of gyrations
N_{max}	maximum number of gyrations

CHAPTER 1 INTRODUCTION

INTRODUCTION

Balanced Mix Design (BMD) is defined as an “asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate, and location within the pavement structure.”^(1,2) Furthermore, the Association of State Highway and Transportation Officials (AASHTO) PP 105-20 Standard Practice for Balanced Design of Asphalt Mixtures describes four approaches (A through D) for a BMD process.⁽¹⁾ Table 1 summarizes the differences in the four BMD approaches in terms of their volumetric and performance requirements, flexibility level, and potential for innovation.⁽³⁾

There are four approaches for BMD. As more experience and confidence is gained with one approach, an agency can evolve to a different approach.

- *Approach A—Volumetric Design with Performance Verification.* This approach starts with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) for determining an optimum binder content (OBC). The asphalt mixture is then tested with selected performance tests to assess its resistance to rutting, cracking, moisture damage, and other distresses at the OBC. If the mix design meets the performance test criteria, the job mix formula (JMF) is established and production begins; otherwise, the entire mix design is repeated using different materials (e.g., aggregates, binders, recycled materials, and additives) or mixture proportions until all of the volumetric and performance test criteria are satisfied.
- *Approach B—Volumetric Design with Performance Optimization.* This approach is an expanded version of Approach A. It also starts with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) for determining a preliminary OBC. Asphalt mixture performance tests are then conducted on the mix design at the preliminary OBC and two or more additional contents. The asphalt binder content that satisfies all of the cracking, rutting, moisture damage, and other distress criteria is identified as the final or target OBC. In cases where an asphalt binder content does not exist in which all the performance test criteria are met, the entire mix design process needs to be repeated using different materials (e.g., aggregates, binders, recycled materials, and additives) or mixture proportions until all of the performance criteria are satisfied.
- *Approach C—Performance-Modified Volumetric Design.* This approach begins with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) to establish preliminary component material properties, proportions, and asphalt binder content. The performance test results are then used to adjust either the preliminary asphalt binder content or the mixture component properties or proportions (e.g., aggregates, binders, recycled materials, and additives) until the performance criteria are satisfied. For this approach, the final design is primarily focused on meeting performance test criteria and may not have to meet all of the mix design volumetric criteria.
- *Approach D—Performance Design.* This approach establishes and adjusts mixture components and proportions based on performance analysis with limited or no State Department of Transportation (DOT) requirements for volumetric properties. The State DOT may set minimum requirements for asphalt binder quality and aggregate properties.

Once the laboratory test results meet the performance criteria, the mixture volumetric properties may be checked for use in production.

These new approaches to asphalt mix design are being implemented or explored by a number of State DOTs to address concerns about pavement performance with the traditional volumetric mix design methods. State DOTs that have already moved forward with implementation activities of BMD within their asphalt pavement program can be at different stages of the implementation process. These agencies have valuable experiences and lessons learned that could facilitate the implementation of a BMD program into practice to improve long-term pavement durability and performance.

Implementation of BMD could be as big of a change as implementation of Superpave binder and mixture, if not bigger.

Table 1. Summary of the BMD Approaches Volumetric and Performance Requirements, Flexibility, and Innovation Potential.

BMD Approach	Volumetric Requirements	Performance Requirements	Flexibility	Innovation Potential
A—Volumetric Design with Performance Verification.	Full compliance.	Full compliance.	Most conservative.	Lowest.
B—Volumetric Design with Performance Optimization.	Full compliance at preliminary OBC.	Performance optimization through moderate changes in asphalt binder content.	Slightly more flexible than Approach A.	Limited.
C—Performance-Modified Volumetric Design.	Some requirements relaxed or eliminated.	Performance optimization by adjusting preliminary asphalt binder content or mixture component properties or proportions.	Less conservative than Approach A and Approach B.	Medium degree.
D—Performance Design.	Limited or no requirements.	Performance optimization by adjusting mixture components and proportions. ^a	Least conservative.	Highest degree.

Notes: ^aA State DOT may set minimum requirements for asphalt binder quality and aggregate properties. Once the laboratory test results meet the performance criteria, the mixture volumetric properties may be checked for use in production.

OBJECTIVE AND SCOPE

The objective of this effort was to identify and put forth positive practices, lessons learned, and challenges from State DOTs when implementing BMD and performance testing of asphalt

mixtures. Positive practices are those successful efforts that are being used or have been used by a State DOT that could also be considered by other agencies. Lessons learned are those experiences and efforts from past activities that could be considered by a State DOT in future planning and activities. Challenges are those efforts that a State DOT has previously or is still in the process of addressing.

BMD is not a cure all. Thickness design, existing pavement distresses (e.g., mitigating reflective cracking), construction troubleshooting (e.g., weak subgrade) need to be addressed.

To accomplish the objective of this effort, information was collected through virtual site visits and other means (e.g., research reports, technical publications, meeting minutes, presentations, training videos, specifications, special provisions, research statement of works, etc.) due to the coronavirus pandemic with seven key State DOTs. This report aims at summarizing the findings and observations from these virtual site visits that can be beneficial to other State DOTs depending on their own stage of implementation for BMD program. The overall scope of this report is to:

1. Identify the BMD approach(es) and performance tests being used or explored by State DOTs including the process for selecting performance tests.
2. Identify positive practices used by State DOTs and asphalt pavement industry during the implementation of BMD for asphalt mix design and production acceptance.
3. Collect and communicate experiences, lessons learned, and challenges with the implementation of performance testing for asphalt mixtures.
4. Identify the observed benefits by State DOTs associated with the use of BMD and performance tests.
5. Identify research and deployment opportunities on the use of BMD and performance testing for asphalt pavements.

STATE DOTs VIRTUAL SITE VISITS

To learn more regarding the details of BMD and performance tests implementation efforts, virtual site visits and interviews of seven key State DOTs were conducted. This often-included interviews with agency personnel, material producers and paving contractors, consultants, and academia along with video tours of many of the laboratories. The participating State DOTs were geographically dispersed across the U.S. (figure 1) and included:

- California DOT (Caltrans).
- Illinois DOT (IDOT).
- Louisiana DOT and Development (LaDOTD).
- Maine DOT (MaineDOT).
- New Jersey DOT (NJDOT).
- Texas DOT (TxDOT).
- Virginia DOT (VDOT).

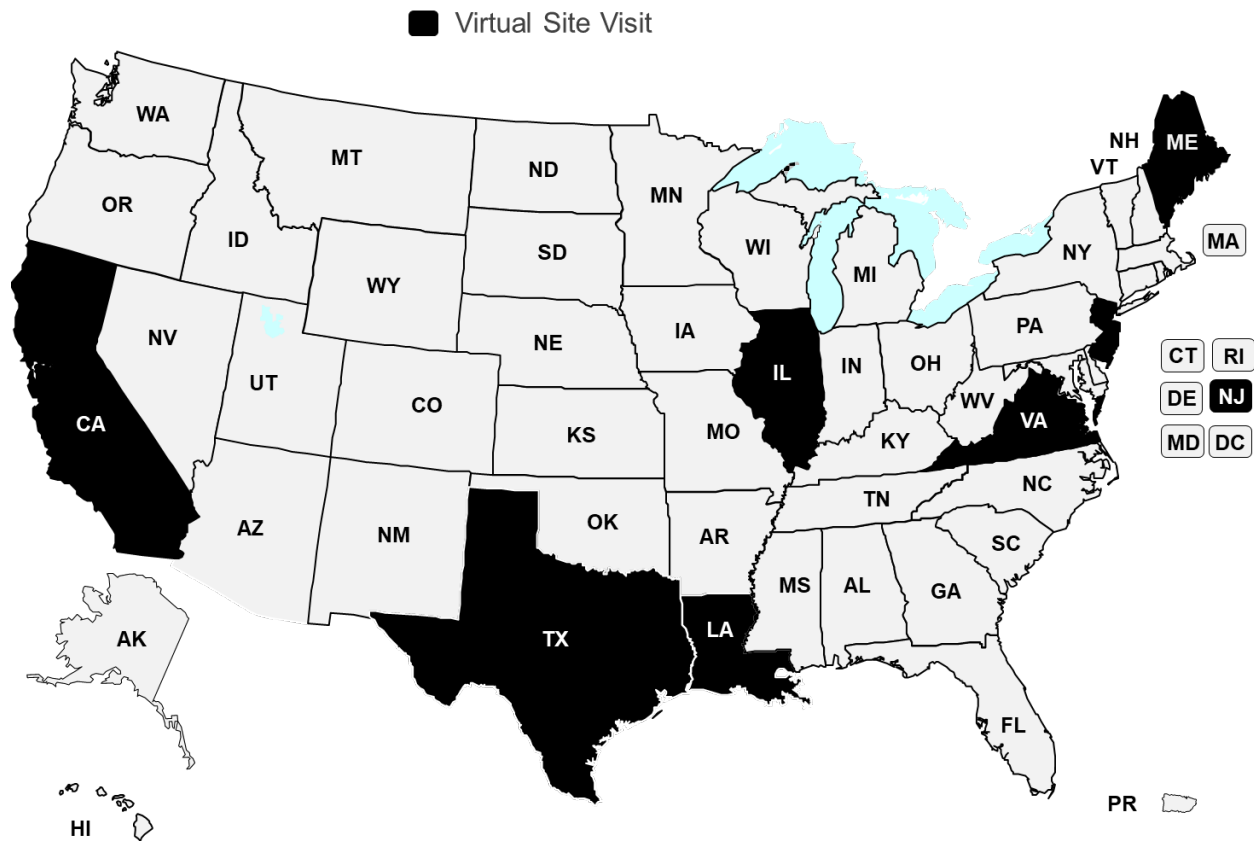


Image: University of Nevada, Reno

Figure 1. Map. Participating State DOTs in virtual site visits for BMD implementation efforts.

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 practices and lessons learned for BMD that can facilitate the implementation of a BMD program into practice at other State DOTs. This often included interviews with agency personnel, contractors, and academia along with video tours of many of the laboratories. The outcomes of each virtual site visit included a report to each FHWA Division Office and State DOT visited on the observations and practices identified.

PROCESS TO IMPLEMENTATION OF BMD

The overall process of implementing BMD as part of mix design approval and quality assurance (QA) can be summarized in eight major tasks that are shown in figure 2. These tasks and associated subtasks were established in collaboration with the National Center for Asphalt Technology (NCAT) based on concurrent activities. The findings and observations are a collaboration from these virtual site visits and NCAT’s other related activities (e.g., BMD regional workshops). These tasks are meant to present and summarize the activities that a State DOT may need to undertake to implement a BMD program. Thus, not all tasks may be applied or considered by a State DOT depending on its organizational structure, staffing level, workspace, annual asphalt tonnage, as well as industry experiences and practices.



Figure 2. Chart. Overall tasks to implementation of a BMD program.

Although there are logical sequences for some of the tasks, there are some cases where tasks may be conducted in parallel or in a different order without any negative consequences. For instance, several activities (e.g., establishing test criteria) can occur in multiple inter-related tasks or subtasks. The following is an overall brief description of the various tasks. Table 2 and table 3 define some key terminologies used in the overall implementation process of a BMD program.

Tasks are not necessarily sequential and may be accomplished concurrently. Depending on the goal, some tasks may not be necessary.

- *Task 1: Motivations and Benefits of BMD.* This task focuses on making sure stakeholders, and in particular for top management, understand why a new approach to asphalt mix design and acceptance is needed and the associated benefits expected with the change. The “why” may be different for different State DOTs.
- *Task 2: Overall Planning.* This task is concerned with understanding the overall implementation process, defining and setting a State DOT’s goals, and determining the resources necessary to achieve those goals with a realistic timeline. Achieving those goals involves coordinated efforts and partnership with stakeholders.
- *Task 3: Selecting Performance Tests.* This task comprises the identification of the primary asphalt pavement modes of distress and selection of relevant mixture performance tests with strong relationship to field performance. This involves planning efforts for validating performance tests.
- *Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.* This task focuses on acquiring equipment for performance testing, managing available resources, conducting initial training, evaluating performance tests, and conducting interlaboratory studies (ILS).
- *Task 5: Establishing Baseline Data.* This task involves establishing baseline data that is critical for the development of performance test criteria and related performance specifications. This includes leveraging previous experiences with performance testing of asphalt mixtures; benchmarking existing mix designs using the selected asphalt mixture performance tests; utilizing shadow projects by obtaining additional samples during the course of the project for performance testing; collecting and analyzing data on production variability of the performance test results; and evaluating the tests sensitivity to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), volumetric parameters (e.g., air voids, voids in mineral aggregates [VMA]), and aging.
- *Task 6: Specifications and Program Development.* This task is concerned with developing mix design criteria that will be used in developing specifications prior to pilot projects. This involves establishing performance test criteria using information gathered from the field validation experiments, variability studies, and baseline data. If desired, preliminary acceptance could also be developed. This would include selecting the appropriate quality measures, acceptance quality characteristics (AQC), and preliminary AQC specification limits for each test method using information from the State DOT’s existing QA program. Selecting appropriate quality characteristics for quality control (QC) can also be completed using information from the aforementioned tasks.
- *Task 7: Training, Certifications, and Accreditations.* This task is focused on developing or updating existing technician and laboratory qualification programs and providing training workshops on initial projects.

- *Task 8: Initial Implementation into Engineering Practice.* This task involves the initial implementation by a State DOT of BMD and performance requirements into their asphalt pavement program. This includes developing the scope for project selection and establishing feedback loops to have coordinated, collaborative, and committed effort towards full implementation of BMD.

Table 2. Primary Goal of Validation of Performance Testing and Benchmarking of Existing Asphalt Mixtures.

Topic	Primary Goal
Validation of Performance Testing	To make sure that performance test results have a strong relationship to field performance.
Benchmarking of Asphalt Mixtures	To determine how existing asphalt mix designs perform using the selected performance tests.

Table 3. Definition of Shadow and Pilot Projects.

Shadow Project	Pilot Project
Existing paving project using conventional acceptance test.	Typical bidding-contracting process with new QA requirements applied.
Performance test results are for informational purposes only.	Performance testing required as part of mix design, verification and acceptance (if part of the goal).

ORGANIZATION OF THE REPORT

This report is organized into eleven chapters as described below:

- Chapter 1 presents the introduction along with the objective and scope of the virtual site visits with the seven key State DOTs. It also includes a summary of the eight major tasks that a State DOT can consider for the overall process of implementing BMD as part of mix design approval and QA.
- Chapters 2 through 8 summarize the findings and observations from each of the seven site visits that were completed. Each chapter includes the State DOT’s motivation for implementing performance testing and BMD, a review of the State DOT BMD approach, a summary of the various implementation activities undertaken by a State DOT, the overall benefits of using performance testing and BMD, as well as the State DOT’s future directions.
- Chapter 9 comprises the positive practices, lessons learned and challenges from lead States that have gone through BMD implementation.
- Chapter 10 summarizes the topics identified and suggested by the visited States for further research, deployment, and technical support.
- Chapter 11 is a concise summary of the implementation efforts for a BMD program.

CHAPTER 2 VIRTUAL SITE VISIT: CALTRANS (SEPTEMBER 2020)

INTRODUCTION

In the late 1990s the asphalt pavement industry was faced with the challenge of building long-life asphalt pavements (LLAPs) that can last more than 30 years using performance-related specifications (PRS) that are based on mechanistic-empirical (ME) design.⁽⁴⁾ In 2003, Caltrans launched a collaborative effort with the asphalt pavement industry and the University of California Pavement Research Center (UCPRC) to test LLAP strategies on a rehabilitation project on the 710 Freeway in Southern California (District 7).^(4,5) The project included both full-depth asphalt sections and asphalt overlays on cracked-and-sealed portland cement concrete (PCC) that were designed to last more than 30 years with minimal maintenance. The design traffic consisted of more than 200 million equivalent single axle loads (ESALs). The 710 Freeway rehabilitation project involved eight 55-hour weekend closures for the construction of LLAPs using fast-track construction to minimize traffic delays and inconvenience to the traveling public. Since then, Caltrans, industry, and academia continued to work together with the goal of developing additional LLAP projects in California. However, the next LLAP project did not occur until 2012 (9 years after the first project), in part due to the Great Recession that started in December 2007.⁽⁴⁾

Between 2002 and 2020, Caltrans funded 5 long-life asphalt pavement projects with PRS tying mixture and thickness designs together.

Between 2012 and 2014 Caltrans designed and built three additional LLAP projects. Two projects were in District 2 on Interstate 5 (I-5)—one just north of the city of Red Bluff and the other on the interstate running through and north of the city of Weed—and one in District 4 on Interstate 80 (I-80) in Solano County between the cities of Dixon and Vacaville.⁽⁴⁾ All projects had design goals of 40-year fatigue (bottom-up or reflective) and rutting (asphalt and unbound layers) service lives. Each project involved new and different contractors with no or limited experience in building LLAPs. Figure 3 shows a geographical map of the 12 Caltrans districts.



Figure 3. Map. Caltrans districts (<https://dot.ca.gov/caltrans-near-me>).

In 2019, a fifth LLAP rehabilitation project on I-5 (Sacramento) was awarded—the project is 15.1 miles long and extends from 1.1 mile south of the Elk Grove Boulevard overcrossing to the American River Bridge. The project costs \$370 million and will rehabilitate pavement, construct new High Occupancy Vehicle (HOV) lanes, replace a pedestrian overcrossing, construct sound walls, install new fiber optic lines and new ramp meters, and extend various entrance and exit ramps. The project is expected to be completed by December 2022.

The overall Caltrans approach for LLAPs comprises the following three major activities (stages): (1) select a project location (including route and post mile range) and develop a conceptual asphalt pavement design; (2) obtain representative materials and establishing performance-related test specifications (criteria) for each of the asphalt mixtures in the pavement design used on the project; and (3) create the final LLAP design for the project utilizing the ME concept and measured properties for locally available materials. The flexural beam fatigue (FBF)—AASHTO T 321 and the repeated simple shear test (RSST)—AASHTO T 320 laboratory testing are implemented in the pavement designs and specifications.^(6,7)

The California ME Analysis and Design (CalME) software design methodology that was first developed in 2000 is used in the process. The CalME is a flexible pavement ME design software that is based on incremental-recursive damage models and materials parameters from repeated load tests for fatigue (FBF) and rutting (RSST), and frequency sweeps for stiffness (FBF). Accelerated pavement testing (APT) using Heavy Vehicle Simulators (HVS) from different studies and some other field sections were used to calibrate the CalME. The ME design provided Caltrans with the tool to consider non-traditional material properties such as rubberized asphalt mixtures, asphalt mixtures with high reclaimed asphalt pavement (RAP) (i.e., RAP up to 40% by asphalt binder replacement) in the pavement design.

The results from the FBF and RSST are used for the mix design and acceptance. In the most recent I-5 project (2019), the RSST was replaced with the repeated load triaxial (RLT) test (AASHTO T 378) after recent challenges in identifying consultants and research institutions with the ability to operate and run the RSST.⁽⁸⁾ The RLT is conducted using the Asphalt Mixture Performance Tester (AMPT). The Hamburg Wheel-Tracking Test (HWTT) was specified for all LLAP projects as a consideration for moisture sensitivity.⁽⁹⁾ The Illinois Flexibility Index test (I-FIT) was specified on the I-5 (Sacramento) project as a shadow test for its potential use as a surrogate cracking test in the future.⁽¹⁰⁾ Neither the HWTT nor the I-FIT results were used in the ME design process. Throughout the years, Caltrans funded and coordinated relevant research with the UCPRC to assure rational implementation of performance testing and PRS.

For non-LLAP or standard projects, Caltrans standard specifications (2018) for Hot-Mix Asphalt (HMA)—Section 39 require the HWTT for rutting performance evaluation using the AASHTO T 324 (modified).^(11,12) The HWTT is implemented for Superpave Type A HMA and Rubberized HMA–Gap Graded (RHMA-G) mixtures. Test criteria are established based on the asphalt mixture type and the asphalt binder performance grade (PG). The AASHTO T 283 is required for the evaluation of asphalt mixtures to moisture susceptibility.⁽¹³⁾ In the case of LLAP projects, performance testing requirements are specified for asphalt mixtures. Table 4 shows a summary of the asphalt mixtures used by Caltrans along with their applications. While an LLAP is designed to last 40 years, the HMA-LL Surface mixture is overlaid with a thin (sacrificial layer) HMA/RHMA-open graded mixture that is intended to be replaced every 12–16 years.

Table 4. Asphalt Mixture Types Used by Caltrans.

Mixture Type		Application
Standard	Type A HMA	Surface, intermediate, or bottom course.
	RHMA-G	Surface course.
LLAP	HMA-LL Polymer Modified Mixture	Surface course.
	HMA-LL Stiff Mixture	Intermediate course.
	HMA-LL Rich Binder Mixture	Bottom course.

BMD APPROACH

In 2014, Caltrans implemented the Superpave methodology for mix design into Section 39 - HMA of the Standard Specifications.⁽¹⁾ The specification requires the use of HWTT (AASHTO T 324—Modified) and the tensile strength (TS) to identify the rutting resistance and moisture susceptibility properties of asphalt mixtures, respectively. The BMD of Type A HMA and RHMA-G for designing and approving JMFs follows Approach A *Volumetric Design with Performance Verification*.

Caltrans has begun looking at a BMD approach for standard projects.

Figure 4 shows a flowchart of the overall BMD for Type A HMA that highlights the major steps for undertaking a mix design according to Caltrans specifications. The requirements for volumetric design and performance testing for Type A HMA and RHMA-G are summarized in table 5 and

table 6. The HWTT criteria is based on the asphalt binder PG; thus, taking into consideration both climate and traffic conditions. The TS criteria is the same for both asphalt mixtures. Currently a cracking test is not required in the Section 39 specification.

The Caltrans approval for JMF comprises the following three major steps. A contractor may start production only if all three steps were successfully completed (figure 4).

1. Caltrans first reviews the proposed JMF submittals from contractor. The review of the JMF needs to show compliance with the specifications.
2. Caltrans verifies the JMF within 12 months before HMA production by testing the asphalt mixture produced at the plant to be used.
3. Caltrans authorizes the verified JMF by proving the tested asphalt mixture is in compliance with specifications.

In the case of LLAP projects, the BMD for designing and approving JMFs follows Approach C *Performance-Modified Volumetric Design*. The RLT (AASHTO T 378, modified) is used to select the OBC for each of the HMA-LL Surface and HMA-LL Intermediate—originally the RSST test (AASHTO T 320) was used. The FBF test (AASHTO T 321, modified) is used to determine the asphalt mixture response to fatigue at the selected OBC. The HWTT (AASHTO T 324, modified) is used to evaluate the moisture sensitivity response of each of the asphalt mixtures. Table 7 shows the specification implemented on the on-going I-5 (Sacramento) LLAP project. It should be noted that the criteria is project specific.

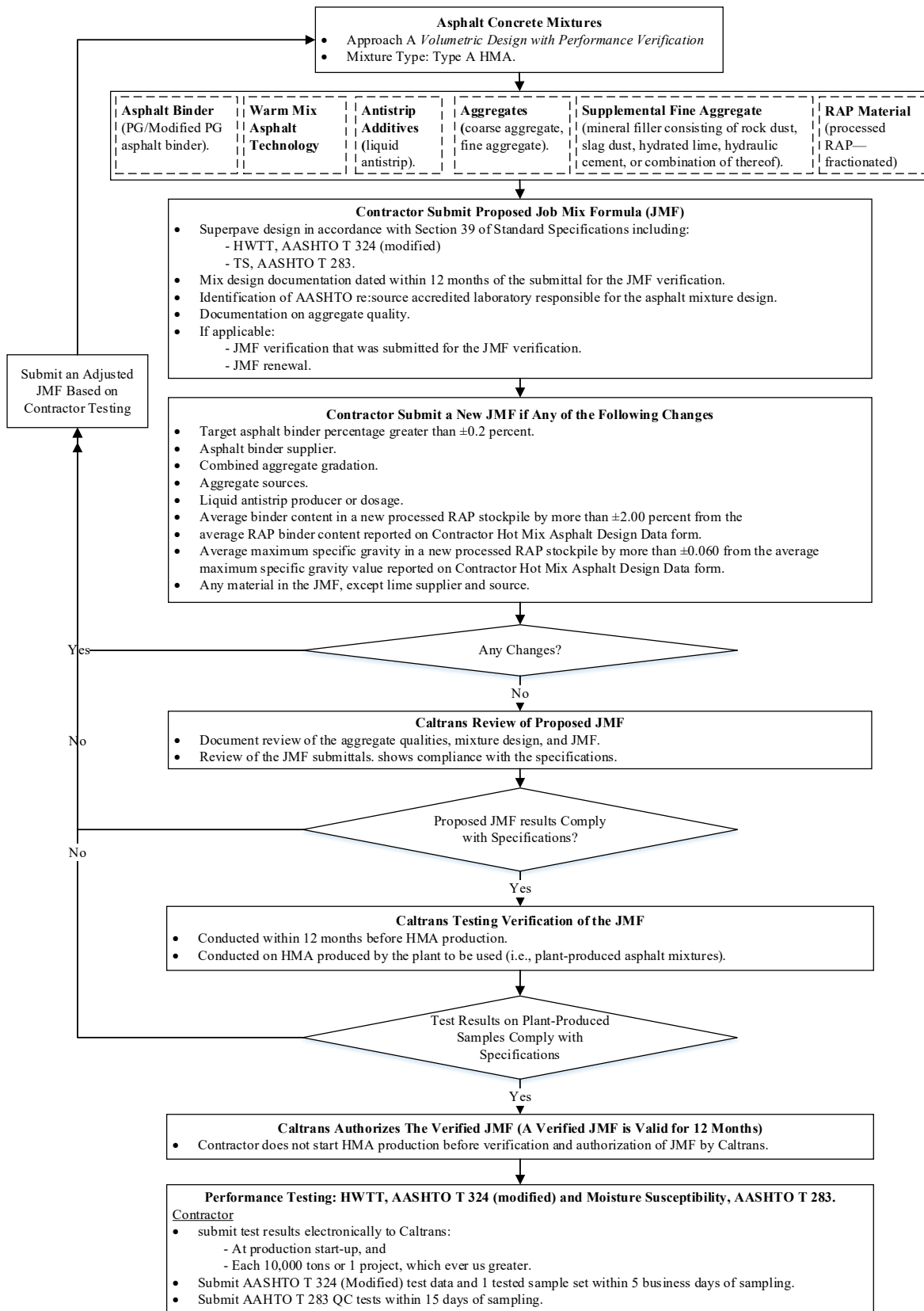


Figure 4. Chart. Overview of Caltrans mix design process for Type A HMA.

Table 5. Caltrans Specifications for Mix Design Volumetric Properties (Standard Projects).

Quality Characteristic	Test Method	Requirement	
		Type A HMA	RHMA-G
Air voids content (%)	AASHTO T 269	> 8.0 at $N_{initial}$ = 4 at N_{design} (= 5 at N_{design} for 1-inch aggregate) > 2.0 at N_{max}	= 4 at N_{design}
Gyrations compaction (No. of gyrations)	AASHTO T 312	$N_{initial} = 8$ $N_{design} = 85$ $N_{max} = 130$	$N_{design} = 50-150$
VMA (min. %) Gradation: No. 4 3/8 inch 1/2 inch 3/4 inch 1 inch With NMAS = 1 inch With NMAS = 3/4 inch	MS-2 Asphalt Mixture Volumetrics (Type A HMA); SP-2 Asphalt Mixture Volumetrics (RHMA-G)	16.5–19.5 15.5–18.5 14.5–17.5 13.5–16.5 13.5–16.5 14.5–17.5	18.0–23.0 18.0–23.0
Dust proportion	MS-2 Asphalt Mixture Volumetrics (Type A HMA); SP-2 Asphalt Mixture Volumetrics (RHMA-G)	0.6–1.3	Report only

Table 6. Caltrans Specifications for Mix Design and Acceptance Performance Testing (Standard Projects).

Mixture Type	HWTT (Modified AASTO T 324), Number of Wheel Passes at 0.5-inch Rut Depth ¹				HWTT (Modified AASTO T 324), Number of Wheel Passes at Inflection Point ¹				TS (AASHTO T 283), psi	
	PG 58	PG 64	PG 70	PG 76 or higher	PG 58	PG 64	PG 70	PG 76 or higher	Dry	Wet
Type A HMA	≥ 10,000	≥ 15,000	≥ 20,000	≥ 25,000	Report only	Report only	Report only	Report only	≥ 100	≥ 70
RHMA-G	≥ 15,000	≥ 15,000	≥ 20,000	–	Report only	Report only	Report only	–	≥ 100	≥ 70

–Not applicable.

¹Test plant-produced asphalt mixture.

The overall Caltrans approach for LLAP comprises the following three major activities (stages). Figure 5 summarizes the overall framework for both the asphalt mixture and structural pavement section designs for an LLAP project.

- Stage 1 consists of selecting a project location (including route and post mile range) and developing a conceptual asphalt pavement design.
- Stage 2 consists of obtaining representative materials and establishing criteria for each of the asphalt mixtures in the pavement design used on the project.
- Stage 3 consists of creating the final LLAP design for the project utilizing the ME concept and measured properties for locally available materials.

Table 7. Mix Design and Acceptance Performance Testing Requirements for I-5 (Sacramento) LLAP Project.

Design Parameters	Test Method	Sample Air Voids	Requirements		
			HMA-LL Surface	HMA-LL Intermediate	HMA-LL Rich Bottom
Permanent Deformation: ^{1,2} Minimum number of cycles to 3% permanent axial strain at 122°F.	AASHTO T 378 (Modified) ³	Mixture Specific ⁴	941	3,007	–
Beam stiffness (ksi): ^{2,5} Minimum stiffness at the 50 th cycle at the given testing strain level.	AASHTO T 321 (Modified) ³	Mixture Specific ⁴	210 at 893×10 ⁻⁶ inch/inch	782 at 433×10 ⁻⁶ inch/inch	707 at 420×10 ⁻⁶ inch/inch
Beam fatigue: ^{2,5} Minimum of 1,000,000 cycles to failure at this strain. Minimum of 250,000 cycles to failure at this strain.	AASHTO T 321 (Modified) ³	Mixture Specific ⁴	495×10 ⁻⁶ inch/inch 893×10 ⁻⁶ inch/inch	220×10 ⁻⁶ inch/inch 443×10 ⁻⁶ inch/inch	269×10 ⁻⁶ inch/inch 420×10 ⁻⁶ inch/inch
Semicircular beam fracture potential: ² Minimum flexibility index (FI).	AASHTO T 393 (formerly AASHTO TP 124) ³	Mixture Specific ⁴	3.0	0.5	0.5
Moisture Sensitivity: Minimum repetitions for rut depth of 0.5 inch at 122°F.	CT 389 (AASHTO T 324 Modified) ³	Per Test Method	20,000	20,000	–

–Not required.

¹Tested unconfined, 4.4 psi contact stress, and 70 psi repeated axial stress.

²Average value determined from tests on 3 specimens and calculated as the geometric mean.

³Included in the testing procedure, LLP-AC3, “Sample Preparation and Testing for Long-Life Asphalt Concrete Pavements” located in the Information Handout.

⁴6 ± 0.5% for HMA-LL Surface and HMA-LL Intermediate mixtures, and 3 ± 0.5% for HMA-LL Rich Bottom mixture all following AASHTO T 331.

⁵Tested at 10 Hz load frequency and 68°F test temperature.

Specification limits are selected based on the 95 percent confidence interval for the given property based on replicate tests (Caltrans accepts 95 percent of the risk of laboratory test variability). The limits applied to plant-produced asphalt mixture in accordance with specifications. While contractors can use laboratory- or plant-produced asphalt mixtures to develop their preliminary designs, a plant-produced asphalt mixture must be used for mix design testing. Conventional design requirements for aggregate gradation, asphalt binder content, and volumetric properties are also included in the specifications; e.g., air void content, aggregate specifications, voids in mineral aggregate (VMA), voids filled with asphalt (VFA), dust proportion (DP), and tensile strength ratio (TSR). Because of the time requirements for these performance tests, the quality control and acceptance testing during construction are still based on conventional tests (i.e., air voids, VMA, etc.).

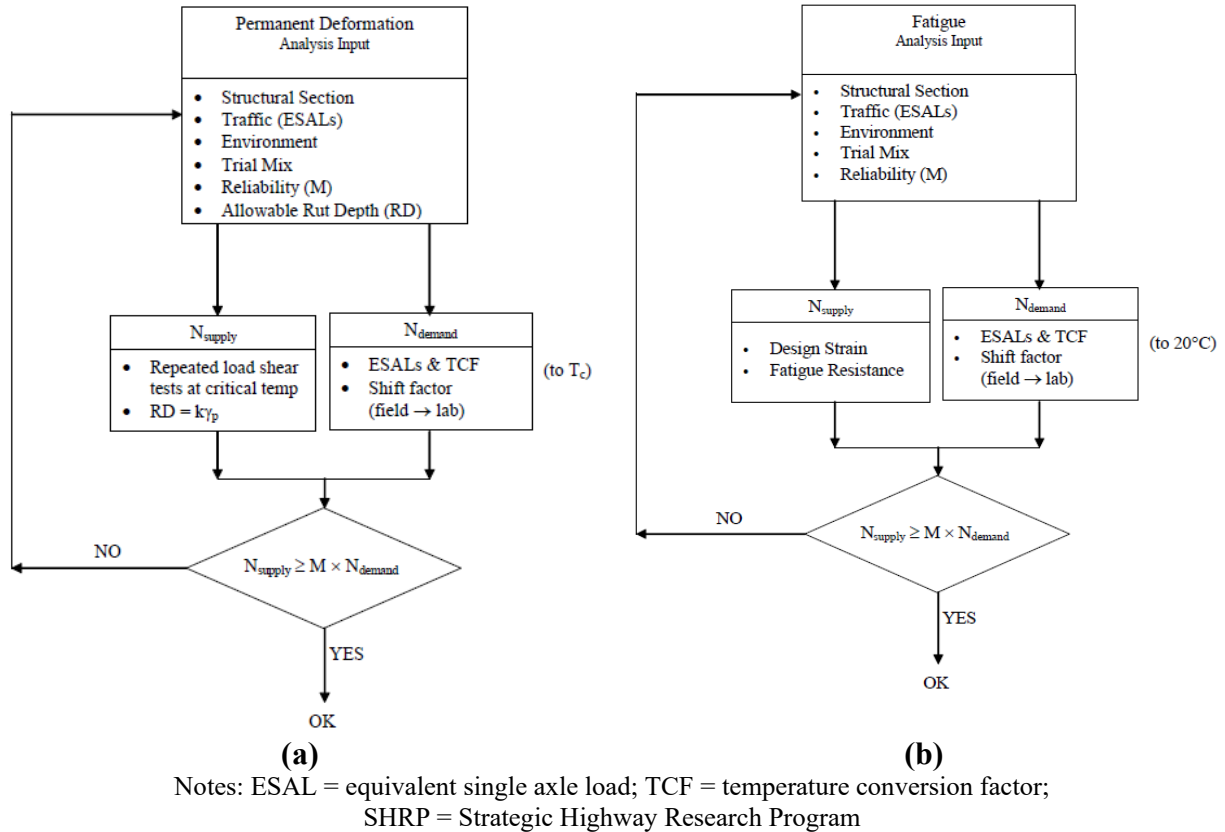


Figure 5. Chart. Framework for asphalt mix design: (a) performance deformation system; (b) fatigue system (SHRP-A 415 augmented by research from UCPRC).

In comparison to AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design” and AASHTO R 35, “Standard Practice for Superpave Volumetric Design for Asphalt Mixtures,” the following key modifications are implemented by Caltrans to their volumetric design criteria (table 5 to table 8 table 10):^(14,15)

- Specified lower number of gyrations for design of asphalt mixtures.
- Increased the VMA requirement for Type A HMA by 0.5–3.5 percent for the 4.75, 9.5, 12.5, and 19.0 mm mixtures and by 1.5–4.5 percent for the 25.0 mm mixtures.
- Increased the VMA requirement by 4–9 percent for RHMA-G and by 5–10 percent for the 12.5 and 19.0 mm mixtures.
- Increased by 0.1 percent the upper limit of the dust-to-asphalt binder ratio requirement for Type A HMA.
- Excluded the requirement for the dust-to-binder ratio for RHMA-G.

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by allowing more asphalt binder into the mixture without jeopardizing its resistance to rutting (the lower the N_{design} and the higher the VMA, the higher the asphalt binder content for a given air void level).

Table 8. Summary of Caltrans Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Mixture Types	
	Type A HMA	RHMA-G
Number of Design Gyration (N_{des})	↓	↓
Density at N_{des}	↔ / ↓	↔
Density at Initial Number of Gyration ($N_{initial}$)	↑	–
Density at Maximum Number of Gyration (N_{max})	↔	–
Design Binder Content	–	–
Voids in Mineral Aggregate (VMA)	↑	↑
Voids Filled with Asphalt (VFA)	–	–
Dust-to-binder ratio	↑ UL	R
HWTT Passes at 12.5 mm Rut Depth	Min	Min
TS – Dry	Min	Min
TS – Wet	Min	Min

–indicates not applicable or not specified; Min=minimum; Max=maximum; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit; R=report only.

IMPLEMENTATION PROCESS OF BMD

The following section summarizes Caltrans experience with BMD implementation in terms of the eight tasks identified in figure 2. As noted before, the tasks organize the various activities involved in the implementation of a BMD program that a State DOT can consider as part of its own effort to putting BMD into practice.

Task 1: Motivations and Benefits of BMD.

The asphalt pavement industry was faced with the challenge of building LLAPs that can last more than 30 years using PRS that are based on ME design. It was desired to predict and extend performance of LLAPs by creating mechanistic ties between the pavement design and mix design. A second reason was to use a performance test to replace Hveem stability with the implementation of Superpave.

The “why” was to build LLAPs that could last more than 30 years using PRS and ME design.

Task 2: Overall Planning.

Identification of Champions. Internally, there was a champion that took the lead in the implementation effort. Continuous communication and partnership within Caltrans between the Pavement Program, Materials Engineering and Testing Services (METS), and Division of Construction helped in validating and refining performance test criteria.

Establishing a Stakeholders Partnership. The implementation of performance tests on projects involved a cooperative effort between Caltrans, industry, and UCPRC for both design development and construction evaluations. This effort was carried under a Flexible Pavement Task Group for Long Life Pavement Rehabilitation Strategies (LLPRS) Program. Things did not always go smoothly, but Caltrans took the lead in keeping the implementation effort moving forward.

The LLAP utilized asphalt mixture and structural pavement section designs based on Strategic Highway Research Program (SHRP) developed technologies, results from the California APT Program, and innovations in construction specifications and requirements.

Establishing Goals. Caltrans has been investing and funding performance testing for LLAP projects throughout the state. A total of 5 LLAP projects have been funded between 2003 and 2020. Caltrans will establish a project selection criteria based on asphalt mixture tonnage usage for LLAP projects (e.g., 50,000 to 100,000 tons). Caltrans has also been leading and investing significantly in the process to develop and implement a BMD for all of its asphalt mixtures.

Mapping the Tasks. Research roadmaps were developed in order to assure proper and successful implementation of performance testing. Figure 6 shows a pavement research roadmap for the “PRS for Asphalt Superpave and QC/QA” with a scope of developing performance tests and specifications for use with asphalt pavement of all types. Figure 7 shows a pavement research roadmap for the ME design asphalt with a scope of establishing ME approaches and tools for asphalt surface pavement evaluation, design, and analysis. Both roadmaps list the major tasks/projects to be accomplished under “Concept,” “Research,” “Development,” and “Implementation.” The listed tasks/projects are identified as either completed, on-going, or planned for the future. It is clear from figure 6 and figure 7 that significant efforts and investments are needed for full and complete implementation for asphalt pavement of all types.

For LLAPs, comprehensive and detailed research roadmaps were developed for asphalt mixture and thickness designs. Roadmaps included tasks to be completed under Concept, Research, Development, and Implementation.

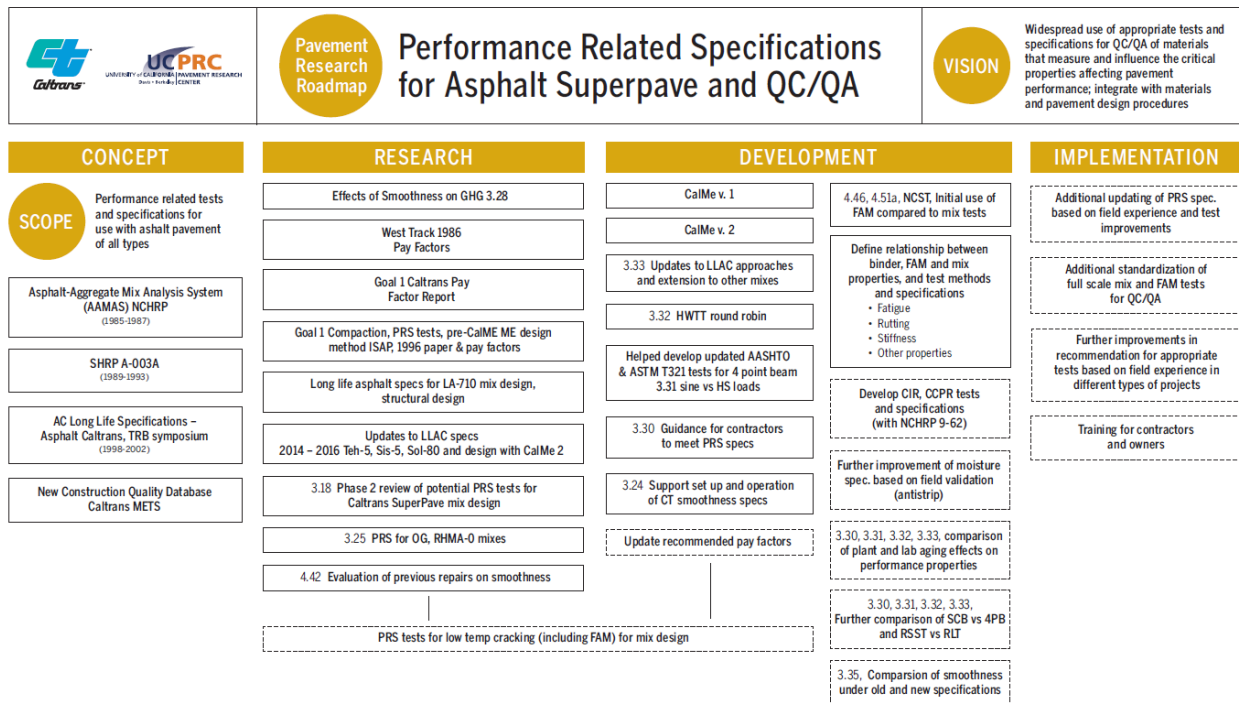


Figure 6. Chart. Caltrans pavement research roadmap for “PRS for Asphalt Superpave and QC/QA.”

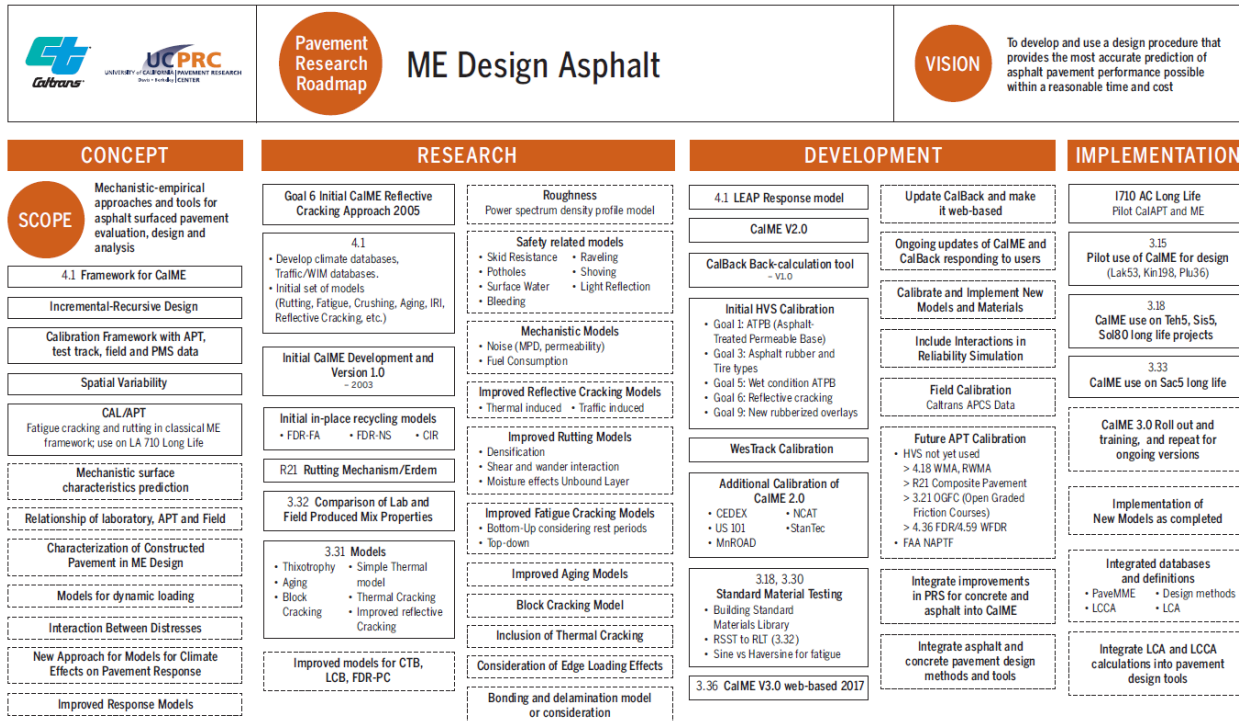


Figure 7. Chart. Caltrans pavement research roadmap for “ME Design Asphalt.”

Identifying Available External Technical Information and Support.

Caltrans launched a collaborative effort with UCPRC to test LLAP strategies on a rehabilitation project on the 710 Freeway in Southern California (District 7). The coordination with UCPRC continued with four additional projects as candidates arose.

External support from UCPRC was a key.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. All critical distresses were considered as the challenge was building LLAPs that can last more than 30 years.

Identifying and Assessing Performance Test Appropriateness. The HWTT was implemented in 2015 along with Superpave for standard projects to replace the Hveem stability test. Caltrans selected the HWTT after reviewing related specifications and procedures for other State DOTs. The following performance tests have been used for developing LLAP projects. The tests, which were selected based on past SHRP studies, provide properties and performance models necessary for the ME pavement design and performance life prediction in CalME.

- For permanent deformation (rutting): the RSST at constant height (AASHTO T 320) has been used until recently, this test got replaced with the RLT test (AASHTO T 378) using the AMPT. This transition from the RSST to the RLT test is because of the lack in a critical mass of numbers of deployed and operational RSST devices.
- For fatigue cracking: the four-point bending beam fatigue test using controlled displacement (adapted from AASHTO T 321) is used.
- For stiffness: the four-point bending beam frequency sweep test (adapted from AASHTO T 321) or the initial flexural stiffness in four-point bending beam fatigue test is used.

Caltrans is considering and evaluating suitable performance tests for routine asphalt mix design, QC, and acceptance testing. The RLT test is being evaluated for use in mix design and acceptance testing for rutting evaluation. On the other hand, the I-FIT and the ideal cracking tolerance (IDEAL-CT) test (ASTM D8225) are being evaluated for cracking resistance.⁽¹⁶⁾ The performance tests for both cracking and rutting need to be calibrated against the currently used performance tests for LLAP projects and field performance. This effort involves an aging study to evaluate differences in plant- and laboratory-produced asphalt mixtures. Caltrans ultimate goal is to incorporate the tests into standard Superpave mix design procedures and construction specifications.

All of the specimens for the performance tests are prepared using rolling wheel compaction (RWC) that was originally developed during SHRP (AASHTO PP3). The RWC method is aimed to simulate the aggregate structure obtained in asphalt mixtures during pavement construction. The AASHTO procedures are modified for performance testing evaluation of asphalt mixtures and are published in the Caltrans Lab Procedure – LLP-AC3.

The top three factors for Caltrans in selecting a performance test for routine use were: material sensitivity, field validation, and repeatability.⁽¹⁷⁾ The test should be sensitive to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), air voids, and aging. Caltrans recognizes that a repeated load test is likely to have a higher variability in test results. Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of Caltrans motivations for implementation of performance tests. In the selection process, consideration is also given to the capability of the performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures (based on historical field performance of asphalt mixtures). The test results of local asphalt mixtures should not contradict known and observed field pavement performance. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications.

Other important factors for Caltrans are sample preparation, specimen conditioning and testing time, and equipment cost. The duration needed for sample preparation, specimen conditioning, and testing have been key considerations for Caltrans in the selection of performance tests for routine use. The aim was also to maintain a low-cost for specimen fabrication and testing equipment. Having qualified and trained technicians help to reduce the impact this factor might have on the overall implementation effort of performance tests.

Validating the Performance Tests. Caltrans based its selection of HWTT criteria on specifications from other State DOTs, and revised based on comparison of test results to historical field pavement performance. Caltrans continues to validate the HWTT criteria by sampling and testing of asphalt mixtures, monitoring field pavement performance, and comparing the results. Caltrans and in collaboration with industry continues to update and modify the HWTT criteria as found needed.

The CalME is calibrated from APT using HVS from different studies and some other field sections. The calibration of the CalME was achieved by comparing simulated to measured

distress data. The calibrations increase the confidence in the CalME models for use on the standard and LLAP projects.

Caltrans continues to validate the performance test criteria through long-term performance monitoring of constructed LLAP projects and ME analyses. This is accomplished by conducting distress surveys along with non-destructive testing (NDT) to estimate the in-situ properties and damage. The NDT-based information is then used in the CalME to estimate pavement distresses, which in turn are compared to observed field distresses. After over 17 years of service life, the 710 Freeway rehabilitation project is still crack free with its performance being validated in CalME. Thus, providing Caltrans and industry with additional confidence in the overall approach and in particular in the CalME simulations and calibrations.

Asphalt mixture performance tests were validated with CalME and ongoing field performance monitoring of the LLAP projects.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. While central and district laboratories are very well equipped to run and analyze HWTT and TS implemented for the BMD approach, Caltrans continues to rely on UCPRC for all other performance tests required on LLAP projects (i.e., RLT, FBF, I-FIT, and IDEAL-CT). A large number of private (e.g., contractors, consultants) laboratories that conduct business in California are capable of conducting the HWTT as shown in the Statewide Independent Assurance Database (SIAD) for laboratory accreditation and tester certification information (<https://sia.dot.ca.gov/index.php?r=lab%2Fsearch>).

One of the main challenges for contractors was the turn-around time between ordering the testing equipment and receiving the equipment on-site for use on the project. An example would be the waiting time for the contractor AMPT machine and the beam cutting saw for the AASHTO T 378 (RLT) and AASHTO T 321 (FBF), respectively. Both equipment took five months to arrive from Europe. To ensure the asphalt mix design schedule could be maintained, this required sending plant-produced asphalt mixture out to university laboratories that could roll the beams and cut them for testing—sometimes it takes 1-2 months for the test results for a single trial mix design. The contractors took the risk and purchased the equipment prior to the job being awarded to shorten the mix design timelines.

Evaluating Performance Testing. Caltrans constantly revises and updates the test methods as deemed necessary based on new findings and through continuous communication and coordination with researchers, industry, vendors, etc. They are continuously improving and updating test procedures and analysis methodologies that improve test repeatability. For example, in response to raised concerns with HWTT variability and the specified number of passes to maximum rut depth for RHMA-G, the Pavement and Materials Partnering Committee formed a working group comprised of industry representatives and Caltrans to evaluate AASHTO T 324 (modified) test protocol and specifications. The working group came up with 12 modifications that were implemented through a new California Test 389, specification changes necessary to implement California Test 389, and changes to the specified number of passes to

maximum rut depth for RHMA-G. These changes were included in the Revised Standard Specifications published April 17, 2020.

There appeared to be a disconnect between laboratory mixed data used to develop the specifications and the contractor requirement to base their asphalt mix designs on plant-produced material. Because mix design acceptance is based on plant-produced material only, contractors

A disconnect was observed between performance tests data of laboratory-produced asphalt mixtures used to develop the specifications and plant-produced material.

were unsure whether to spend time testing laboratory mixed and laboratory compacted specimens or just proceed straight to testing plant-produced asphalt mixtures. Contractors did not realize if there would be a difference in performance test results between the two methods. As it turns out, plant-produced asphalt mixtures typically exhibited different performance test results than laboratory-produced asphalt mixtures. Due to test turnaround time issues (mainly for FBF), contractors decided to proceed with plant trials only to optimize the blend before doing the actual mix design. This led to unanticipated costs and a high number of plant hot drops to complete the designs.

Having technicians dedicated to performance testing would accelerate the turnaround time for test results. Establishing an approved JMF is very time consuming (could take 1–2 years) and requires significant investments and resources from the contractor. The cost and time for establishing a JMF is expected to reduce by understanding and gaining more experience with the process.

Conducting Inter-Laboratory Studies. As part of Caltrans Superpave implementation initiative, the reproducibility of the HWTT (AASHTO T 324) results was evaluated through a round robin testing program that included 20 participating laboratories (UCPRC-RR-2016-05, 2015–2016): 5 district laboratories; 14 industry laboratories; 1 UCPRC. The study included different makes and models for the HWTT devices. Each laboratory conducted four HWTTs: two of the tests were conducted on Superpave gyratory-compacted (SGC) specimens prepared by UCPRC, and the other two were conducted on SGC specimens prepared by each of the participating laboratories using loose asphalt mixture supplied by UCPRC. A typical plant-produced asphalt mixture was used in this study. The following HWTT results were reported: rut depth after 5,000, 10,000, 15,000, and 20,000 wheel passes; number of passes to 0.5 inch (12.5 mm) rut depth; creep slope; stripping slope; and stripping inflection point. Raw test data from certain laboratories were also submitted to UCPRC for further analysis.

In summary, the single-operator variability was found to be relatively high and the between-laboratory variability was shown to be strongly related to several measurement and result-interpretation aspects that are not fully defined in AASHTO T 324. This between-laboratory variability was reduced when unique criteria were used in the data analysis. Precision indices were determined for only the number of passes to the stripping inflection point. The single-operator and multi-laboratory coefficients of variation (COVs) were 22 and 33%, respectively. The multi-laboratory COV improved to 22% when fixed criteria were used by all laboratories in the analysis. The precision estimates of the number of wheel passes to 12.5 mm could not be determined (very limited number of tests reached this threshold value). Recommendations were made to improve the HWTT single-operator and multi-laboratory variability.

The Caltrans independent assurance program also requires laboratory proficiency testing to evaluate laboratory equipment and practices, tester competence, and the repeatability of the test methods. The Reference Sample Program (RSP) provides laboratories an opportunity to compare their performance relative to the entire population of participating laboratories. In 2018, the RSP proficiency test was based on AASHTO T 324 for RHMA-G (<https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/mets/2018-aashto-t324-rsp-report-all1y.pdf>). A total of 27 State and private laboratories participated in the proficiency testing and scores of “Acceptable” were given to all participating laboratories.

Task 5: Establishing Baseline Data.

Analyzing Production Data. In general contractors were supportive of the BMD and PRS approach as a way to increase the life cycle of asphalt pavements. Continuous communication, dialogue, and partnering with industry helped in balancing both the agency and industry needs and concerns. Based on contractors’ experience with LLAP projects, the following observations were made:

UCPRC provided significant support to contractors and Caltrans for LLAP projects. Contractors’ observations were well documented.

- Changes to asphalt mixtures to get acceptable performance testing values were material and mixture specific.
 - Approached the design process from a BMD perspective and understood each component’s impact on rutting (RLT and HWTT) and cracking (I-FIT and FBF).
 - Virgin binder selection was based on stiffness properties (not just asphalt binder being in compliance with specification).
 - Asphalt binder content was increased to improve cracking performance compared to a typical asphalt mixture used by Caltrans.
 - The impact of RAP binder stiffness on performance tests was examined.
 - Employed a very structured design process for each of the LLAP mixtures and included the following steps with the goal to submit a blend for acceptance testing that would pass (avoid wasting Caltrans and contractor resources and time by submitting designs with a marginal chance of passing).
 - Run an initial trial and measure FBF and RLT performance in relation to specifications.
 - Based on the FBF and RLT performance test results, make the appropriate adjustment to the asphalt mixture to improve the specific property in question.
 - Only one adjustment was made at a time so the impact of that adjustment could be clearly understood.
 - Evaluated gradation impact on performance testing (gradation changes from fine to coarse side of the gradation band, proximity to the 0.45 power curve).
 - Removed natural (rounded) sand and replaced it with manufactured sand (crushed washed dust).
 - Selected the design asphalt binder content at air void contents other than 4.0 percent while realizing the increase in the asphalt binder content positively impacted FBF and I-FIT results.
 - Varied the RAP content in the asphalt mixture while realizing its impact on the asphalt mixture stiffness

- Design process resulted in a mix design significantly different than a typical asphalt mixture used by Caltrans:
 - Included about 0.6–0.8 percent more asphalt binder content (depending on the asphalt mixture).
 - Utilized a different JMF gradation than what is typically used.
 - Excluded the use of natural sand which strains sand and gravel deposits and aggregate production facilities.
 - Selected the OBC closer to a 3 percent air voids content.
 - Required significant focus on understanding differences between coldfeed and post plant gradations and accounting for these differences as part of plant set up and plant production adjustments. The goal was to ensure the material was produced as close as possible to JMF targets, which can be a challenge with coldfeed being the acceptance location for gradation.
- Several challenges and risks existed during asphalt mixture acceptance:
 - Lack of performance test history. Because asphalt mix design acceptance is based on plant-produced material only, contractors were unsure whether to spend time testing laboratory mixed and laboratory compacted specimens or just proceed straight to testing plant-produced asphalt mixtures. Contractors did not understand if there would be a difference in performance test results between the two methods. Due to test turnaround time issues (mainly for FBF), contractors decided to proceed with plant trials only to optimize the blend before doing the actual asphalt mix design. This led to unanticipated costs and a high number of plant hot drops to complete the designs.
 - Test results from FBF (AASHTO T 321, modified) and RLT (AASHTO T 378, modified) appeared to be highly variable between test samples from the same plant-produced asphalt mixture and plant hot drop. Typically, the plant-produced-asphalt mixture had failing RLT test results when the HWTT results for the same mixture had routinely rut depths of only 1.3 to 4 mm with a much higher repeatability compared to the RLT test.
 - Prior to submitting the flexural beam samples to UCPRC for final JMF testing, samples were sent to multiple research laboratories. Samples routinely failed flexural beam stiffness and fatigue specification limits set by the project.
 - Approximately 30 plant hot drops (each a minimum of 100 tons or 20–30 minutes of continuous production) were required for the FBF testing process for the three LLAP mix designs. Multiple hot drops were run with little or no changes to plant setup—this resulted in big swings in RLT and FBF test results for very little or no change in plant setup.
 - There was a concern that a passing blend may not be achievable as contractors had exercised asphalt mixture changes that are known to positively impact performance. Consistent passing results were not observed.
 - There appeared to be a disconnect between laboratory mixed data used to develop the specifications and the contractor requirement to base their asphalt mix designs on plant-produced material.
 - Between bid time and asphalt mix design verification, specifications for both RLT and FBF were changed driving increased effort, time, and cost.

- During production test results were going in and out of specification for RLT test that is being run daily with little or no variability in asphalt binder content or aggregate gradation. This was anticipated based on the performance test variability observed during the acceptance process
- Conducting a trial paving before start of project construction was essential for the paving crew to learn about and how to deal with the asphalt mixtures that will be used during construction by adjusting their construction practices (e.g., compaction efforts, rolling patterns, workability of the rich bottom asphalt mixture, etc.).
- UCPRC has provided significant support related to the new equipment used on the I-5 (Sacramento) LLAP project including joint training and sample exchanges as contractors worked to get their team up to speed and ready for the project. Contractors are very appreciative of UCPRC support.
- Contractors are concerned that the test variability will impact the asphalt mix design re-verification process in 2021 and could result in many plant hot drops (with little to no plant changes) just to arrive at passing results.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. The sensitivity of performance test results to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), volumetric parameters (e.g., air voids, VMA), and aging is an important factor for Caltrans. The use on LLAP projects resulted in new challenges for materials producers and contractors who have never had to relate volumetric mix design parameters to mechanistic parameters from performance tests for fatigue life and rutting resistance. Contractors need to be able to make informed decisions on what changes can be made to the asphalt mixture composition and proportions in order to improve performance and meet applicable specification limits.

Accordingly, Caltrans funded a UCPRC research study (UCPRC-RR-2017-12) to provide asphalt mixture designers and contractors guidance regarding changes to asphalt mix designs to achieve requirements.⁽¹⁸⁾ A guidance was established based on past experience that was then validated and demonstrated using an approved plant-produced asphalt mixture by Caltrans. The plant-produced asphalt mixture was used as the starting point for a set of adjustments applied to the mixture (e.g., adjustments in aggregate gradation, natural sand content, dust-to-binder

A guide to systematically adjust mixtures to meet performance requirements was extremely valuable.

proportion, asphalt binder stiffness). The effects of each adjustment on the mechanistic performance indicators (i.e., stiffness, fatigue resistance, and rutting resistance) were measured and compared. Furthermore, CalME simulations were conducted to evaluate the impact of the performance test results on predicted pavement performance when the asphalt mixture is used as a pavement surface layer. The laboratory test results for the evaluated asphalt mixtures were used as inputs for the CalME analyses. Based on the findings from this study, a flowchart for asphalt mix design guidance was provided as shown in figure 8.

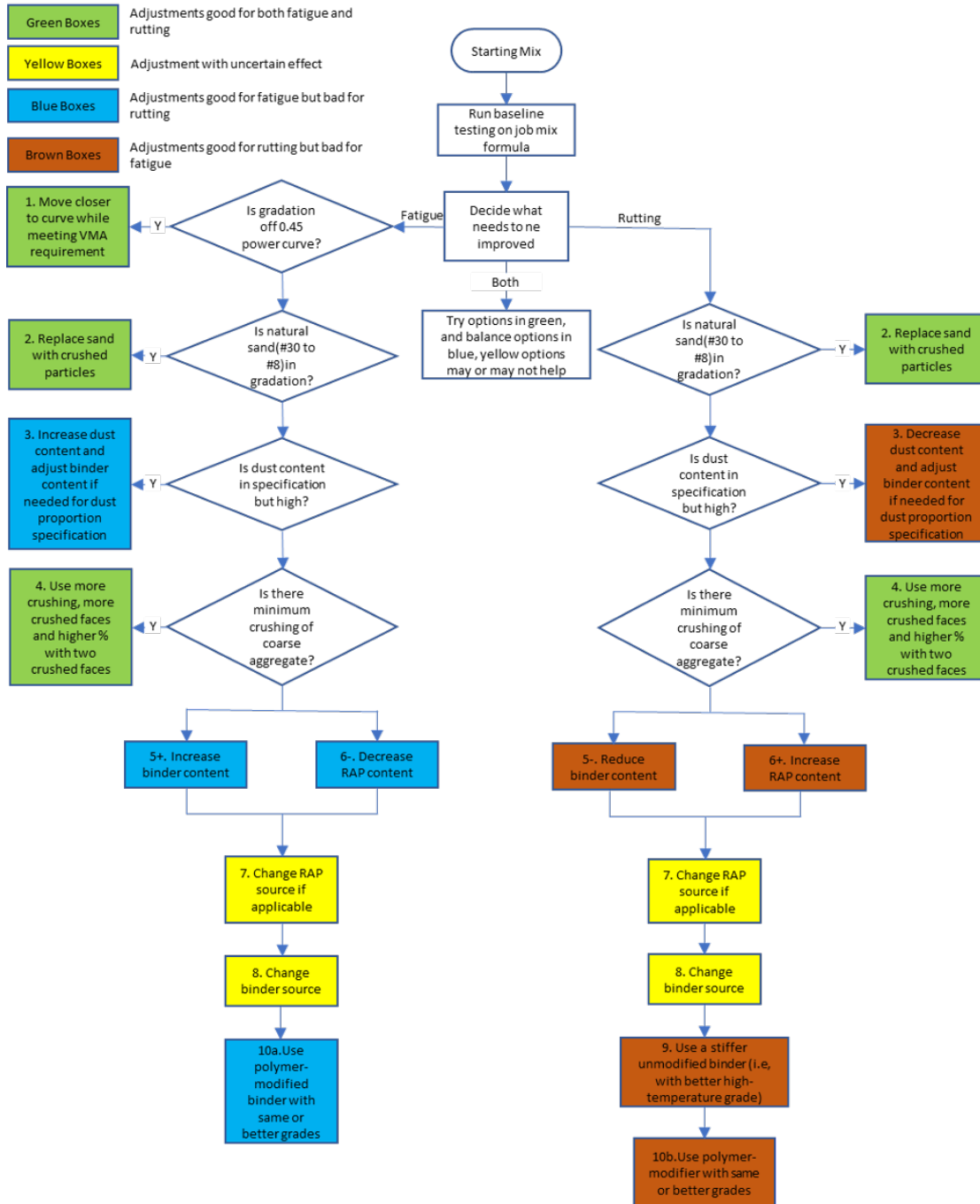


Figure 8. Chart. Revised flowchart proposed for improving the fatigue or rutting performance of an asphalt mixture (UCPRC-RR-2017-12).

Task 6: Specifications and Program Development.

LLAP projects involve minimum requirements for laboratory test results for asphalt mixtures regarding stiffness, rutting performance, fatigue performance, and moisture damage. Contractors are expected to submit JMF with test results on plant-produced asphalt mixtures, showing compliance with the corresponding requirements. Based on the experience from the four

completed LLAP projects between 2002 and 2013, it was observed that the process for mix design and specification development, as well as JMF approval is both time consuming and full of uncertainty for inexperienced contractors.⁽¹⁹⁾ Thus, emphasizing the need to revise and simplify the development and implementation of specifications on LLAP projects without jeopardizing the expected performance from materials and pavement structures.⁽¹⁹⁾

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. The performance tests (AASHTO T 321, AASHTO T 324, AASHTO T 378, AASHTO T 393 (formerly AASHTO TP 124, and AASHTO T 283) are included in both the laboratory accreditation and tester certification.

Recently, Caltrans, local agencies, and industry have established a joint training and certification program (JTCP) to make the certification process more efficient and to ultimately obtain consistent, reliable, quality testing through joint training. The JTCP offers training and certification in “Hot Mix Asphalt (HMA).” The current program does not include performance testing. Caltrans envisions performance testing to be included as part of the training and certification in the future.

Training contractor staff on their own equipment and in their own laboratory environment was extremely helpful.

Before the start of I-5 (Sacramento) LLAP project, UCPRC provided an in-depth training on performance testing and sample preparation to industry and Caltrans. UCPRC staff were allowed to visit contractors’ laboratories and train staff on their machine. Contractors had to quickly develop existing staff for training on a variety of new test methods including AASHTO T 393 (I-FIT), AASHTO T 324 modified (Caltrans Test 389—HWTT), AASHTO T 331 (Corelok), and AASHTO T321 (FBF specimen preparation using RWC). Performance tests required a

higher level of technician competency as compared to what is required for regular QC testing (gradation, asphalt binder content, volumetric properties).

Task 8: Initial Implementation.

The implementation of LLAP projects involved a cooperative effort between Caltrans, industry, and UCPRC for both design development and construction evaluations. Based on contractors’ experience with LLAP projects, the following future activities that can help improving and advancing the overall process were proposed:

- Ensuring the asphalt mix design specification is producible (reduce variability and number of plant hot drops).
 - Little to no plant change is resulting in significant variability in RLT and FBF test results.
- The RLT and FBF test methods being highly variable bring into question the return on investment (ROI) of the design process leading to the following questions:
 - Is the public getting a better asphalt mixture in the most economical way? Would a more simplified BMD system arrive at a similar final design?
 - Is the high capital cost of the AMPT equipment providing sufficient ROI?

- With the performance testing requirements, understanding the difference between coldfeed and post plant gradations and consistently hitting JMF targets on the post plant gradation is critical. The current Caltrans asphalt specification accepts gradation on the coldfeed making it difficult for the contractor to optimize pay on coldfeed while at the same time ensuring post plant gradations are targeting the JMF. It was recommended that Caltrans move gradation acceptance to post plant gradations as to align the gradation acceptance point with the mix design JMF where performance testing and volumetric testing occurs.
- Use of I-FIT and RLT as daily QC tool in production may not be practical due to sample preparation, turnaround time and for the RLT, test method repeatability. In addition, the RLT does not appear to coincide with the low rutting results from the HWTT.
- Utilize the extensive production testing data for RLT, FBF, and I-FIT generated on the I-5 (Sacramento) LLAP project to understand the test method variability and ensure that variability is built into all future Caltrans project specifications.
 - In addition, share this test method variability information with national efforts working on this topic.
- The I-5 (Sacramento) LLAP project has resulted in a very positive partnering experience with Caltrans, UCPRC, and contractors. All teams have worked together on all issues encountered and relationship is very positive and healthy.
- It is believed that the BMD concept will result in better designed longer lasting pavements. Projects like this help advance the contracting community as a whole and contractors were appreciative to be part of this effort.
- The partnership and continuous discussion between Caltrans, industry, and UCPRC is key for a successful implementation of performance tests for design and acceptance of asphalt mixtures.

OBSERVED BENEFITS

The use of performance tests on field projects allowed contractors to optimize the use of recycled materials and still be able to produce asphalt mixtures that are in compliance with Caltrans specifications. The traditional volumetric-based mix design has lots of changes to provide optimum performance for asphalt mixtures with higher RAP content. Performance testing helped in designing asphalt mixtures with higher RAP contents; thus, allowing for the production of economical and environmentally-friendly asphalt mixtures without jeopardizing performance.

No problems were encountered with constructing asphalt pavements using a BMD mixture. The asphalt mixtures designed using performance tests were in general easier to compact in the field and to reach target in-place density, mainly due to the increase in the asphalt binder content.

In summary, the performance tests used on LLAP projects helps to ensure that as-built materials meet the performance requirements assumed in ME pavement structural designs. For the existing LLAP projects no major pavement maintenance activities have been warranted yet other than regularly scheduled preventive maintenance. Furthermore, it provides Caltrans with a system to evaluate non-traditional material properties such as plastic-modified or high RAP and RAS asphalt mixtures.

FUTURE DIRECTION

Caltrans plans to expand the use of LLAP-project approach where the top asphalt layer is high rut resistant, the intermediate asphalt layer is stiff and rut resistant, and the bottom asphalt layer is rich in asphalt binder with high resistance to fatigue cracking. It also plans on implementing a cracking test for Superpave asphalt mixtures used on standard projects. The following summarizes key activities for Caltrans:

- Continue to work on pilot projects and related research studies for the implementation of performance testing for routine asphalt mix design, quality control, and acceptance testing. Modify performance specifications and testing equipment as needed.
- Complete the CalME software evaluation and calibration including the performance testing on HMA Type A and RHMA-G asphalt mixtures from different geographical regions within California.
- Conduct HVS testing of trial sections including the evaluation of cold-in place recycling as a base layer, thick lift RHMA-G pavement, coarse aggregate versus fine aggregate size asphalt mixtures (19 mm versus 12.5 mm), high RAP and reclaimed asphalt shingles (RAS) asphalt mixtures, and RHMA-G asphalt mixtures with 5–10 percent RAP aggregate.
- Establish a project selection criteria based on asphalt mixture tonnage usage for LLAP projects (e.g., 50,000 to 100,000 tons).
- Plan for additional training to laboratory technicians and design engineers to cope the potential future challenges associated with BMD and the LLAP design approach.
- Continue to improve and revise the asphalt mixture guidance that was established to support mixture designers and contractors with their decision making regarding changes to asphalt mix designs to achieve performance test requirements

The full implementation effort needs to be supplemented with proper communication, training, and education activities. Contractors will need to be educated on what changes can be made to the asphalt mixture composition or proportions in order to make informed and cost-effective decisions to improve performance and meet applicable specification limits.

CHAPTER 3 VIRTUAL SITE VISIT: IDOT (AUGUST 2019)

INTRODUCTION

IDOT typically places 4–8 million tons of asphalt mixture a year (about 4.2 million tons of asphalt mixture were placed in 2019). The gas tax and fee increases approved in 2019 are expected to sustain the placement of about 7–8 million tons a year. The IDOT standard asphalt mixtures are specified in Section 1030 of the Standard Specifications for Road and Bridge Construction.^(20, 21) The specifications comprise high ESAL, low ESAL, and stone matrix asphalt (SMA) mixtures. A summary of the asphalt mixtures along with their applications is shown in table 9. The primary differences in the specifications for the High ESAL and Low ESAL mixtures are allowable manufactured sand content and asphalt binder replacement.

IDOT specifications for asphalt mixtures currently require the HWTT for rutting performance evaluation using the Illinois modified AASHTO T 324.⁽²²⁾ The HWTT has been fully implemented into specifications since 2012. Since January 2021, IDOT specifies the Illinois Flexibility Index Test (I-FIT) using the Illinois modified AASHTO T 393 during mix design verification and production testing for all asphalt mixtures.⁽²²⁾

IDOT used a 2-phased process for implementation of performance testing. HWTT and I-FIT were fully implemented in 2012 and 2021, respectively.

Table 9. Asphalt Mixture Types Used by IDOT.

Mixture Type	Nomenclature	Binder Course	Surface Course
High ESAL	IL-19.0	X	–
High ESAL	IL-9.5	X	X
High ESAL	IL-4.75	X	–
Low ESAL	IL-19.0L	X	–
Low ESAL	IL-9.5L	X	X
SMA	≤ 10 Million ESALs	X	X
SMA	> 10 Million ESALs	X	X

–indicates not applicable.

Performance testing was implemented due to concerns with performance of recycled mixtures.

RAP and RAS are widely used in asphalt mixtures in Illinois. With the increased use of such materials, IDOT observed premature failure or reduced performance of their asphalt mixtures. The permanent deformation resistance of the asphalt mixtures was improved with the use of RAP and RAS, as demonstrated with low rut depths in the HWTT. Softer PG of binders were used with certain levels of RAP and RAS. IDOT’s adoption of the HWTT, which promoted increased levels of RAP and RAS, raised concerns that asphalt mixtures with, in particular, increased RAP and RAS contents, are drier, brittle, and more susceptible to premature cracking. Accordingly, IDOT started, and in coordination with the industry, to examine the use of a cracking performance test to complement the HWTT during asphalt mix design verification and production. A cracking test was needed to mainly address the commonly observed premature cracking in asphalt pavement overlays from the increased use of RAP and RAS. IDOT funded and coordinated relevant research with the Illinois Center for Transportation (ICT) at the University of Illinois at Urbana-Champaign (UIUC) to develop an effective cracking test.

BMD APPROACH

In January 2016, IDOT developed a Special Provision for *Hot-Mix Asphalt – Mixture Design Verification and Production (Modified for I-FIT Data Collection)* to require the use of the I-FIT to identify the cracking resistance properties of as-produced asphalt mixture by using the flexibility index (FI) parameter.⁽²³⁾ In January 1, 2020, the special provision was revised to expand I-FIT, including surface mixtures that have been long-term oven aged, to all asphalt mixtures but only for information purposes. In September 2020, IDOT revised the special provision to specify I-FIT for all asphalt mixtures which was inserted into all asphalt paving contracts beginning in January 2021.

Figure 9 shows a flowchart of the overall BMD approach that highlights the major steps for undertaking an asphalt mix design according to IDOT specifications. The IDOT requirements for volumetric design and performance testing for all asphalt mixtures are summarized in table 10 and table 11. The HWTT criteria are based on the binder PG; thus, taking into consideration both climate and traffic conditions. The I-FIT criteria are the same for all asphalt mixtures, except as proposed for IL-4.75 and SMA mixtures. The TSR criterion is the same for all asphalt mixtures.

Table 10. IDOT Specifications for Mix Design Volumetric Properties.

Mixture Type		N_{design}	Binder Content (%)	Design Target Density (%)	VMA (Minimum %)				VFA (%) ¹	Dust-to-Binder Ratio	Drain-down (%)
					NMAS (mm)						
					19	12.5	9.5	4.75			
High ESAL	IL-19.0	50	–	96.0	13.5	–	–	–	65–78	≤ 1.0	–
		70	–	96.0	13.5	–	–	–	65–75	≤ 1.0	–
		90	–	96.0	13.5	–	–	–	65–75	≤ 1.0	–
	IL-9.5	50	–	96.0	–	–	15.0	–	65–78	≤ 1.0	–
		70	–	96.0	–	–	15.0	–	65–75	≤ 1.0	–
		90	–	96.0	–	–	15.0	–	65–75	≤ 1.0	–
IL-4.75	50	–	96.0	–	–	–	18.5	76–83	≤ 1.0	≤ 0.3	
Low ESAL	IL-19.0L	30	4.0–8.0 [†]	96.0	13.5	–	–	–	–	≤ 1.0	–
	IL-9.5L	30	4.0–8.0 [†]	96.0	–	–	15.0	–	65–78	≤ 1.0	–
SMA	≤ 10 MESALs	50	–	96.0	–	16.0	–	–	75–80	–	≤ 0.3
	> 10 MESALs	80	–	96.0	–	17.0	–	–	75–80	–	≤ 0.3

–indicates not applicable.

¹excluded beginning in 2022.

Table 11. IDOT Specifications for Mix Design Performance Testing.

Mixture Type		HWTT (Illinois Modified AASHTO T 324), ≤ 12.5 mm Rut Depth at a Minimum Number of Wheel Passes				FI (Illinois Modified AASHTO T 393)		TS (Illinois Modified AASTO T 283)		
		PG 58-xx (or lower)	PG 64-xx	PG 70-xx	PG 76-xx (or higher)	Short-Term Aging	Long-Term Aging [#]	Conditioned TS, psi ¹		TSR
								Non-Polymer PG	Polymer modified PG ⁵	
High ESAL	IL-19.0	≥ 5,000	≥ 7,500	≥ 15,000	≥ 20,000	8.0	4.0*	≥ 60	≥ 80	≥ 0.85
	IL-9.5			≥ 10,000 [†]	≥ 15,000 [†]					
	IL-4.75			–	–					
Low ESAL	IL-19.0L	–	–	–	–	8.0	4.0*			
	IL-9.5L	–	–	–	–	8.0	4.0*			
SMA	≤ 10 MESALs	≥ 5,000	≥ 7,500	≥ 15,000	≥ 20,000	16.0	10.0			
	> 10 MESALs	–	–	–	–	16.0	10.0			

–indicates not applicable.

¹maximum required unconditioned TS of 200 psi excluded beginning in 2022.

[†]beginning in 2021.

[#]required for surface courses only beginning in 2022.

*production mixture requirement. Mix design long-term aging FI is minimum of 5.0.

⁵except polymer modified PG XX-28 or lower binders shall have a minimum TS of 70 psi.

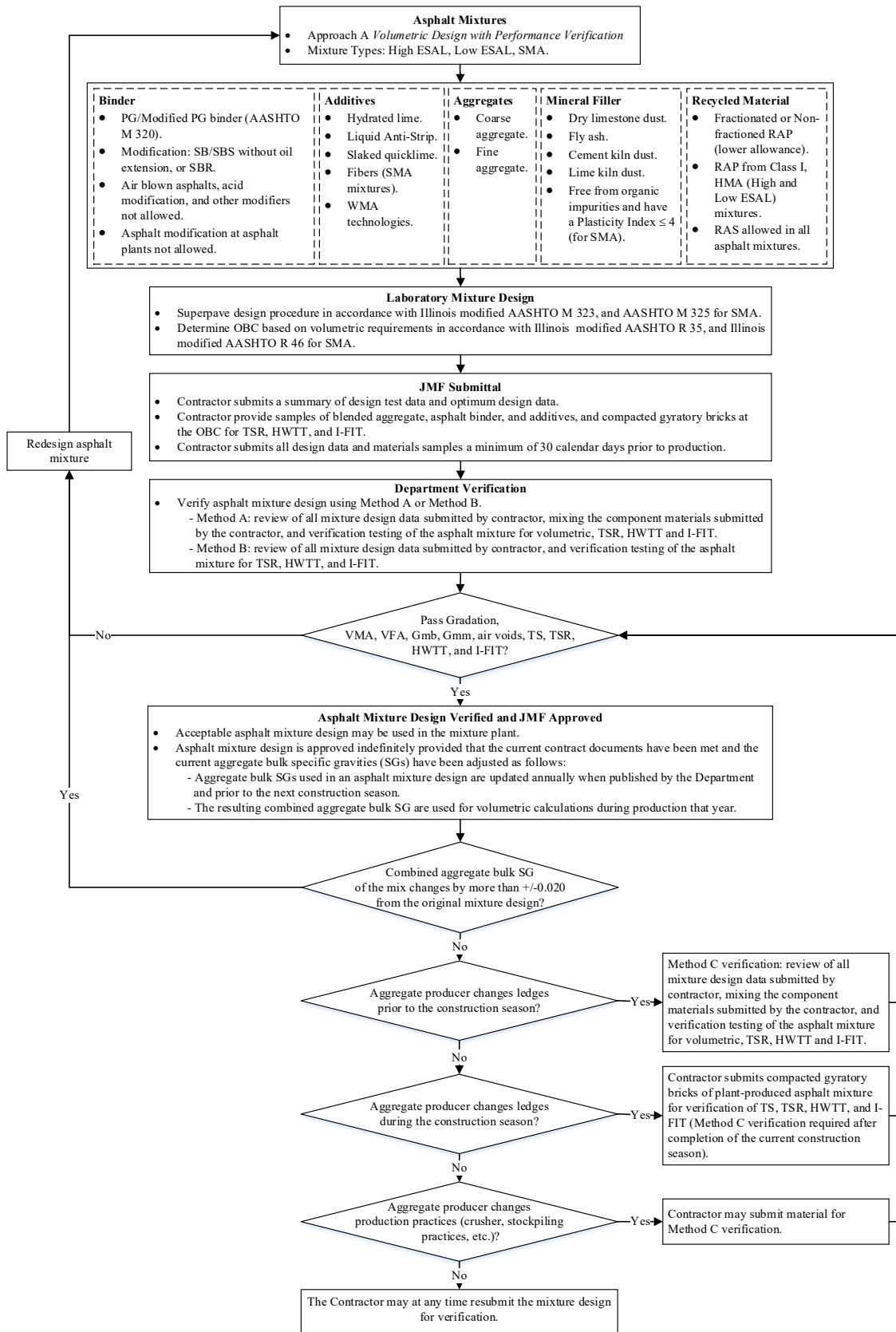


Figure 9. Chart. Overview of IDOT BMD process.

IDOT’s BMD for designing all asphalt mixtures and approving JMFs follows *Approach A– Volumetric Design with Performance Verification*. Meeting the specified volumetric properties first was the main reason for IDOT to select Approach A; asphalt mixture designers should be able to understand what is needed to create a stable and durable asphalt mixture by understanding the role of each component in mixture volumetric properties. While originally IDOT did not relax any of the specified volumetric properties, the acceptable VFA range requirement was excluded in the 2022 standard specifications.^(20, 21)

During mix design, the contractor submits prepared Superpave gyratory samples to IDOT for performance verification testing. Table 12 summarizes the needed testing, and number and size of prepared gyratory samples to be submitted by the contractor. It should be noted that, during asphalt mixture verification, IDOT districts and contractors may complete the moisture resistance testing (unconditioned and conditioned TS) prior to I-FIT and HWTT. Table 13 summarizes the short and long-term conditioning of laboratory and plant-produced asphalt mixtures established by IDOT for asphalt mixtures including warm mix asphalt (WMA).

Table 12. IDOT Specified Samples for Verification Testing.*

Mixture Type		HWTT	I-FIT	TS
High ESAL	Binder Mixture	2–160 mm tall bricks.	1–160 mm tall bricks.	6–95 mm tall bricks.
	Surface Mixture	2–160 mm tall bricks.	2**–160 mm tall bricks.	6–95 mm tall bricks.
Low ESAL	Binder Mixture	–	1–160 mm tall bricks.	6–95 mm tall bricks.
	Surface Mixture	–	2**–160 mm tall bricks.	6–95 mm tall bricks.

*samples of compacted gyratory bricks with 7.5±0.5% air voids that are prepared and submitted by contractors.

**one 160 mm tall brick for short term aging and one for long-term aging of surface mixture.

–indicates not applicable.

Table 13. Summary of Short and Long-Term Conditioning of Laboratory and Plant-Produced Asphalt Mixtures by IDOT.*

Conditioning	Laboratory-Produced Asphalt Mixture			Plant-Produced Asphalt Mixture		
	Volumetrics	TS	HWTT or I-FIT	Volumetrics	TS	HWTT or I-FIT
Short-Term Oven Aging	1 or 2 hours of loose mixture at compaction temperature	1 or 2 hours of loose mixture at compaction temperature	1 or 2 hours (3 or 4 hours for WMA) of loose mixture at compaction temperature	0 hours	0 hours	0 hours (for WMA, 2 hours of loose mixture at compaction temperature)
Long-Term Oven Aging	0 hours	0 hours	<u>I-FIT</u> : 72 hours on compacted and notched specimen at 95°C	0 hours	0 hours	<u>I-FIT</u> : 72 hours on compacted and notched specimen at 95°C

*When two different values are present within a single cell, the correct value is based on whether low or high absorptive aggregates are used.

IDOT currently allows binders to be modified with either a styrene-butadiene/styrene-butadiene-styrene copolymer (SB/SBS) without oil extension, or a styrene-butadiene rubber (SBR). Air blown asphalts, acid modification, and other modifiers are not allowed. Asphalt modification at the plants is also not allowed. In order to address the industry request for allowing the use of other types of modifiers, IDOT initiated a study in 2018 to develop a systematic binder screening protocol. Preliminary findings from the study show promising results for the difference in critical temperatures for low temperature testing (ΔT_c) as a potential component of a screening test for

modified binder performance. The ΔT_c is based on creep stiffness (T_{cont} , S) and m-value (T_{cont} , m), calculated as $\Delta T_c = (T_{cont}, S) - (T_{cont}, m)$. A strong correlation between ΔT_c and FI is observed and an initial threshold value of greater than or equal to -5.0°C after two cycles (i.e., 40 hours) of pressure aging vessel (PAV) is likely to be recommended. This study is also evaluating other rheological and chemical tests to characterize the effects of modifiers in binders.

In comparison to AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design” and AASHTO R 35, “Standard Practice for Superpave Volumetric Design for Asphalt Mixtures,” the following key modifications are implemented by IDOT to their volumetric design criteria (table 10 and table 14):^(14,15)

- Specified lower design number of gyrations (N_{design}) for all asphalt mixtures including the High ESAL, Low ESAL, and SMA mixtures.
- Increased the VMA requirement by 0.5 percent for all the 19.0 mm asphalt mixtures and by 2.5 percent for the 4.75 mm mixtures.
- Specified a draindown requirement for IL-4.75 mixture and SMA.
- Except for SMA mixtures, reduced the dust-to-binder ratio requirement (IDOT uses dust-to-total binder ratio as opposed to dust-to-effective binder ratio).

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by allowing more binder into the mixture without jeopardizing its resistance to rutting (the lower the N_{design} and the higher the specified VMA, the higher the binder content for a given air void level).

Table 14. Summary of IDOT Modifications to AASHTO Standard Volumetric Design Criteria.

IDOT Requirements	Mixture Type					
	IL-19.0	IL-9.5	IL-4.75	IL-19.0L	IL-9.5L	SMA
N_{design}	↓	↓	↓	↓	↓	↓
Density at N_{design}	↔	↔	↔	↔	↔	↔
Density at $N_{max}^{\#}$	↔	↔	↔	↔	↔	↔
Design Binder Content	–	–	–	Range	Range	–
VMA	↑	↔	↑	↑	↔	↑
Dust-to-Binder Ratio*	↓	↓	↓	↓	↓	–
Draindown (%)	–	–	Max	–	–	Max
HWTT Wheel Passes at 12.5 mm Rut Depth	Min	Min	Min	–	–	Min
FI, Short-Term Oven Aging	Min	Min	Min	Min	Min	Min
FI, Long-Term Oven Aging	Min	Min	–	Min	Min	Min
Conditioned TS	Min	Min	Min	Min	Min	Min
TSR	Min	Min	Min	Min	Min	Min

[#] N_{max} =maximum number of gyrations.

*IDOT uses dust-to-total binder ratio as opposed to dust-to-effective binder ratio.

–indicates not applicable or not specified; Min=minimum; Max=maximum; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit.

IMPLEMENTATION PROCESS OF BMD

The following section summarizes IDOT’s experience with BMD implementation in terms of the eight tasks identified in figure 2. As noted before, the tasks organize the various activities involved in the implementation of a BMD program that a State DOT can consider as part of its own effort to putting BMD into practice.

Task 1: Motivations and Benefits of BMD.

The motivation for implementation of BMD in IDOT was primarily two-fold: 1) there were issues with some tender asphalt mixtures and stability problems as a result of the use of natural sand (round particles) in asphalt mixtures; and 2) there was an immediate need to address the observed premature failures of some asphalt pavements as a result of the use of recycled materials in asphalt mixtures. While the use of the HWTT helped addressing the first issue, it resulted in some asphalt mixtures becoming too brittle and more susceptible to premature cracking as a result of higher reclaimed binder ratio (RBR) levels. Thus, IDOT recognized the

The “why” was an immediate need to address premature failures as a result of the use of recycled materials.

potential benefits with the implementation of an asphalt mixture cracking performance test to complement the stability/rutting performance test (i.e., HWTT) during asphalt mix design verification and production.

Task 2: Overall Planning.

Identification of Champions. State DOT champions were committed to implementing the BMD program and provided leadership for the various implementation activities. Thus, IDOT has been leading and investing significantly in the process to develop and implement BMD for all of its asphalt mixtures. Contractors were also generally supportive of the BMD approach as a way to increase the life cycle of asphalt pavements.

IDOT communicated with stakeholders the need and the anticipated enhancements in the quality of asphalt mixtures by having a cracking performance test to address, in particular, the commonly observed premature reflective cracking in asphalt pavement overlays. This helped IDOT in securing the necessary management support and commitment from the State DOT throughout the BMD implementation process to fund pertinent activities such as research, equipment purchasing, pilot projects, training and certification programs, etc.

Support was obtained to develop a cracking test which was needed to mainly address the commonly observed premature cracking in asphalt pavement overlays from the increased use of RAP and RAS. IDOT funded and coordinated relevant research with the ICT at UIUC to assure rational development of an effective performance test.

External support from ICT at UIUC was a key.

Establishing a Stakeholders Partnership. In 2018, IDOT assembled an “Implementation Task Force” with industry that comprised QC managers, Illinois Asphalt Pavement Association (IAPA) representative, FHWA division office representative, and engineers from IDOT (Central Office and Districts). Continuous communication, dialogue, and partnering with industry helped in balancing both the State DOT and industry needs and concerns. IDOT has also an established

partnership with academia to help in supporting critical and pressing research needed as part of the development of BMD. The Implementation Task Force agreed on the following action plan items:

- Increase RBR by 5 percent across the board for all asphalt mixtures in conjunction with the implementation of the I-FIT cracking test requirements.
- Allow binder modifiers once a binder performance test is developed based on the findings from the ICT project R27-196 *Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements* (2018–2021).
- Adopt “Perpetual Mix Designs” that are approved indefinitely. The initial asphalt mix design verification must meet HWTT and I-FIT in addition to volumetric and moisture damage requirements. The asphalt mix design calculations are to be revised on an annual basis to incorporate the annually published aggregate bulk specific gravities.
- Implement higher FI thresholds for SMA and IL-4.75 asphalt mixtures.
- Conduct round robin studies on an annual basis.

Doing Your Homework (Identifying the Issues, Identifying Resources, and Reviewing Literature). IDOT identified two issues with their asphalt mixtures. The first was related to the use of natural sand (round particles) in asphalt mixtures that resulted in some mixtures having a tender behavior and stability problems. The second was related to the use of recycled materials in asphalt mixtures that resulted in some mixture having premature cracking failures. After a critical review of available literature, current resources, and other State DOTs experiences, IDOT selected the HWTT to address the first issue. Several individuals from IDOT traveled to Texas in April 2011 to learn about HWTT program in Texas that has been successfully used in their mix design selection for several years. In the case of the second issue, IDOT saw the need for a new performance test to address the cracking resistance of their asphalt mixtures. Accordingly, resources were committed to fund necessary research studies to develop and implement the I-FIT procedure.

Establishing Goals. IDOT’s goal has been the application of the BMD program onto all State projects for asphalt mix design and acceptance using a phased approach.

The goal for the application of BMD was for all projects for mix design and acceptance.

Identifying Available External Technical Information and Support. IDOT has planned and engaged with local universities to develop the needed performance tests.

Developing an Implementation Timeline. Figure 10 summarizes the I-FIT implementation timeline by IDOT. Several research studies were planned and undertaken to develop the performance tests needed for implementing BMD into engineering practice. In creating the timeline, IDOT generally chose to advance BMD annually. Each year they advanced accordingly with the general plan: one pilot project per district, two pilot projects per district, interstates and statewide implementation.

A timeline was used to guide a phased implementation of projects.

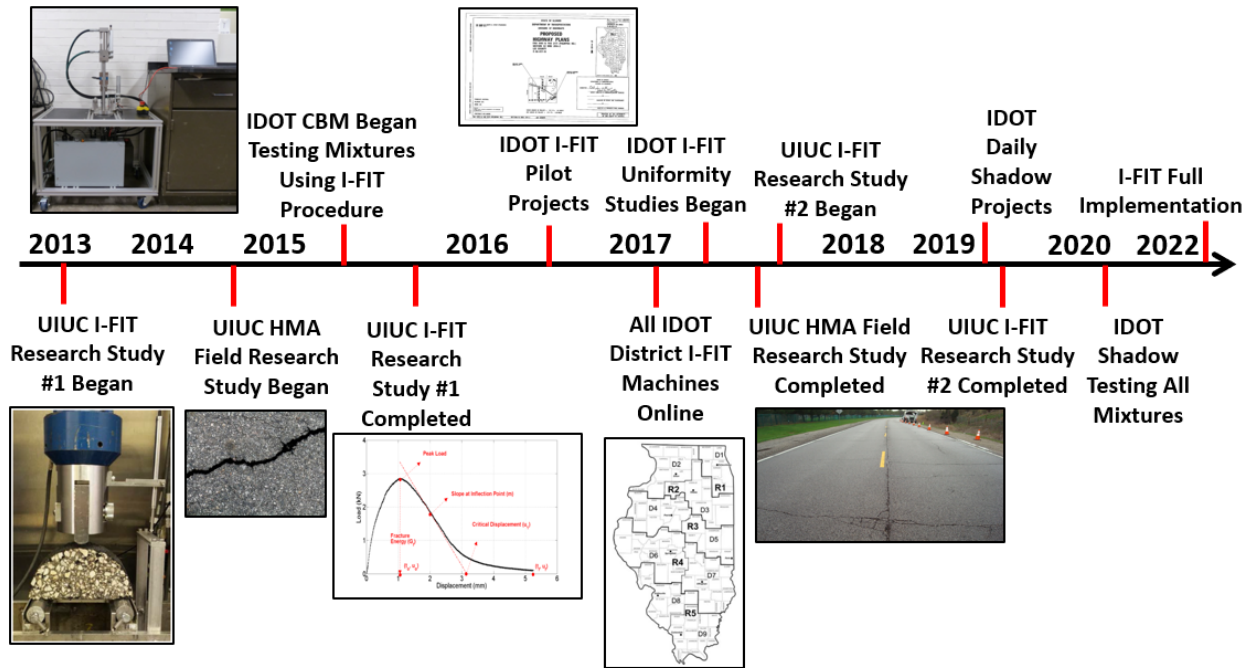


Figure 10. Chart. IDOT I-FIT implementation timeline.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. Rutting and premature cracking were the two primary asphalt pavement modes of distress identified by IDOT to be considered in the BMD process.

Rutting and premature cracking were the distresses that needed addressing.

Identifying and Assessing Performance Test Appropriateness. The top three factors for IDOT in selecting a performance test were: material sensitivity, field validation, and repeatability.⁽¹⁷⁾ The test should be sensitive to asphalt mixture component properties or proportions (e.g., aggregates, binders, recycled materials, additives), air voids, and aging. IDOT recognizes that a test that is considerably sensitive to materials will likely have a higher variability in test results. Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of IDOT’s motivations for implementation of performance tests. In the selection process, consideration was also given to the capability of the performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures (based on historical field performance of asphalt mixtures). For IDOT, the test results of local asphalt mixtures should not contradict known and observed field pavement performance. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications.

Other important factors for IDOT are sample preparation, specimen conditioning and testing time, and equipment cost. The duration needed for sample preparation, specimen conditioning, and testing have been key considerations for IDOT in the development of test criteria and the implementation of performance tests into the specifications. This is tied to the ability of testing

aged specimens that are representative of a future critical pavement condition for cracking while keeping in mind the need for a quick turnaround time for test results. The aim was also to maintain a low-cost for specimen fabrication and testing equipment.

With these factors in mind, IDOT developed its own cracking performance test for asphalt mixtures through research with UIUC.

Four techniques were used to validate the I-FIT.

Validating the Performance Tests. IDOT used four approaches to validate their selected performance tests for BMD that are summarized below:

- I-FIT testing was conducted on asphalt mixtures that were used at the FHWA’s Accelerated Loading Facility (ALF) at the Turner-Fairbank Highway Research Center (TFHRC). The ALF data was used in the initial development of FI minimum criteria and was based solely on fatigue cracking. While this was vitally important, it did not account for reflective cracking that is the most commonly observed mode of distress in Illinois.
- The I-FIT procedure and FI threshold of 8.0 were further validated through ICT research project R27-161 Construction and Performance Monitoring of Various Asphalt Mixes (2014–2017). A series of five experimental projects involving 16 mixtures tested using I-FIT were constructed to better determine the life cycle cost and performance of pavement overlays using various levels of RBR from use of RAP and RAS. The RBR for these asphalt mixture overlays varied from 15 to 48 percent. The ICT R27-161, which focused on reflective cracking, supported the use of 8.0 as a minimum value for FI.
- IDOT also completed I-FIT Pilot Projects in 2016 with annual coring and distress surveys to characterize pavement distress and I-FIT FI. These projects offered an opportunity to better understand the correlation between pavement distress observations and design, production, and field core FI values over time.
- IDOT continues to validate the HWTT and I-FIT criteria by sampling and testing of asphalt mixtures, monitoring field pavement performance, and comparing the results.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. IDOT Central Bureau of Materials (CBM) and district laboratories are very well equipped to run and analyze all performance tests implemented for the BMD approach. This includes all necessary equipment for sample preparation, fabrication, and conditioning of asphalt mixture specimens. In 2010 and 2011, the CBM purchased 9 HWTT devices from a single manufacturer. One device was given to each district laboratory (Districts 2–9) and the CBM laboratory. District 1 purchased their own HWTT device around the same time. In 2015 and 2016 the CBM purchased 10 I-FIT machines from a single manufacturer and 10 tile saws. An I-FIT machine and a tile saw were given to each district laboratory and the CBM laboratory. In total there are approximately 34 HWTT and 30 I-FIT devices in IDOT, university laboratories, and private laboratories (e.g., contractors, consultants).

IDOT is decentralized. A bulk purchase was used to equip each district with performance tests.

Managing Resources. In general, funding resources for acquiring and installing new, necessary equipment in laboratories have not been a major issue for IDOT. A few district laboratories (e.g.,

District 6) had to rearrange their laboratory space in order to make room or increase efficiency in laboratory operation. In general, State laboratories were designed and arranged for basic materials testing with minimal room for large and advanced equipment.

Conducting Initial Training. Initially, IDOT helped and supported contractors with performance tests (conducting tests for the contractors, offering training on equipment and test result calculations) to gain knowledge about their own asphalt mixtures. Instructional videos on HWTT and I-FIT were also prepared and shared with technicians.

Technicians reported that instructional videos were very helpful.

Evaluating Performance Testing. IDOT funded the research study to evaluate long-term aging effects on asphalt mixtures using the I-FIT, and to develop a corresponding long-term oven aging protocol. The aging protocols were developed for laboratory-produced laboratory-compacted (LPLC) and plant-produced laboratory-compacted (PPLC) specimens. The long-term aging for I-FIT specimens is 72 hours at 95°C in accordance with the following procedure:⁽²⁷⁾

Long-term aging protocols for the I-FIT were developed through a research project.

- Place the four (4) I-FIT test specimens, notched side facing down, on a tray (pan), with a non-stick “barrier” (e.g., parchment paper, cooking mat, heavy duty aluminum foil) between the test specimens and the tray.
- Place the tray with the specimens in a pre-heated force-draft oven set at 95±3°C (203±5°F).
- Leave the specimens (undisturbed) in the oven at this temperature for 72±1 hours.
- Remove the entire tray from the oven and place in front of a cooling fan at room temperature for at least one hour.
- If the specimen is not cooled in front of a fan, allow the specimens to cool at room temperature overnight.
- Remove the specimen from the “barrier.”
- After the specimens have cooled and the “barrier” has been removed, proceed with testing procedure.

Conducting Inter-Laboratory Studies. The AASHTO T 324 and AASHTO T 283 performance tests have no information regarding the precision and bias of the test method. This may create a potential issue if two separate laboratories achieve different test results for the same asphalt mixture. Nonetheless, the IDOT test results are considered the test of record for any project.

Annual round robins are conducted, which provide valuable information on test variability.

IDOT completes HWTT and I-FIT round robins on an annual basis and have done this since 2012 for HWTT and 2017 for I-FIT. The round robins help to understand the variability in the test and to provide contractors with comparison data between their device, the IDOT district’s device, and the CBM’s device. These annual round robins provide valuable checks on equipment and technician performance.

The number of participating laboratories in the round robin studies varies from year to year. For instance, in 2019, the Ontario Ministry of Transportation (MOT), Massachusetts DOT, and Vermont Agency of Transportation were added to the I-FIT Round Robin participants list

(Wisconsin, Missouri, and Indiana DOTs have participated for multiple years). Table 15 summarizes the number of participating laboratories in IDOT round robins for the past three years. Generally, over 20 and 30 laboratories participate every year in the HWTT and I-FIT round robins, respectively.

Table 16 summarizes the I-FIT round robin goals for each year. In all round robin studies, a surface asphalt mixture was used in an attempt to minimize the impact of segregation. The data from the 2017–2019 IDOT I-FIT round robins were used to develop the precision statement as shown in the AASHTO T 393. A bias statement is not possible because there is no universal reference in asphalt mixtures.

Table 15. IDOT Round Robin Participants.

Test	No. of Participants			Laboratory Participants					
	2017	2018	2019	IDOT		Contractors / Consultants	University*		Other State DOT and Province MOT
				CBM	Districts		UIUC	Auburn	
HWTT	27	29	35	X	X	X	X	–	–
I-FIT	30	34	35	X	X	X	X	X	X

*NCAT at Auburn University

–indicates did not participate in round robin.

Table 16. IDOT I-FIT Round Robin Goals and Descriptions.

Round Robin Study	Sub Round Robin Studies	Goals	Description
2017 I-FIT*	Round 1: Testing	Evaluate effects of testing.	Ready to test I-FIT specimens that were cut from 160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
	Round 2: Cutting and Testing	Evaluate combined effects of specimen preparation (sawing) and testing.	160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory cut the 160 mm tall gyratory bricks into I-FIT test geometry and tested the I-FIT specimens.
	Round 3: Compacting, Cutting, and Testing	Evaluate combined effects of compaction, specimen preparation, and testing on FI variability.	Loose asphalt mixtures were provided to each laboratory. Each participating laboratory compacted the gyratory samples to specified height, cut 115 mm gyratory into I-FIT test geometry, and tested the I-FIT specimens.
2018 I-FIT*	Round 1(A): Testing	Evaluate effects of gyratory cylinder height on FI.	Ready to test I-FIT specimens that were cut from 160 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
	Round 2(B): Testing	Evaluate effects of gyratory cylinder height on FI.	Ready to test I-FIT specimens that were cut from 150 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
	Round 3(C): Testing	Evaluate effects of gyratory cylinder height on FI.	Ready to test I-FIT specimens that were cut from 115 mm tall gyratory bricks were provided to each laboratory. Each participating laboratory tested the I-FIT specimens.
2019 I-FIT	–	Evaluate combined effects of compacting, preparing, and testing I-FIT specimens.	A loose asphalt mixture was provided to each laboratory. Each participating laboratory compacted the gyratory samples to a specified height (after identifying the weight needed to meet $7.0 \pm 1.0\%$ air voids), cut gyratory samples into I-FIT test geometry, and tested the I-FIT specimens.
2020 I-FIT	–	Evaluate the variability of FI values in the as produced (short-term aged) and long-term aged conditions.	Preliminary test results did not show a significant difference in the COV of FI values for short-term and long-term conditioned specimens.

* all three rounds utilized the same mixture.

–indicates not applicable.

It should be noted that the precision statement developed for AASHTO T 393 was based on 4 replicate specimens.⁽¹⁰⁾ However, the Illinois modified AASHTO T 393 is based on the trimmed mean for three replicate specimens.⁽²²⁾

- When four individual I-FIT specimens with air voids that are within specification are tested, the FI value that is farthest from the average of the four test specimens is discarded to lower the variability of the average FI value that is reported. The test specimen that is discarded is removed from the calculations of average and COV for peak load, post-peak slope, fracture energy, and FI.

The precision and bias for the HWTT have not yet been developed. IDOT can benefit from on-going studies at other State DOTs.

Task 5: Establishing Baseline Data.

Reviewing Historical Data & Information Management System. Historical data on field performance of asphalt mixtures in Illinois was reviewed and used in the selection process of the performance tests. In other words, the test results of local asphalt mixtures need to agree with known and observed field pavement performance.

Conducting Benchmarking studies. IDOT completes in-house research studies to better understand asphalt mixture performance including testing of asphalt mixtures sampled from shadow and pilot projects. Furthermore, IDOT funds ICT research projects to evaluate new materials (e.g., binder modifiers, SMA mixtures with local aggregate) and to develop new test protocols (e.g., I-FIT). These ICT research studies provide information on performance test sensitivity.

Currently, IDOT has large databases of HWTT and I-FIT test results. For example, the I-FIT database includes more than 3,000 test sets that are being evaluated and analyzed. The following are some characteristics of the current I-FIT database:

- Four specimens are typically tested per asphalt mixture.
- The average reported FI value is based on the closest 3 tested specimens (trimmed mean).
- The database includes the eleven 2016 pilot projects (laboratory-produced, plant-produced, and field core samples) and other various samples. The database also includes data from the other 70 plus projects constructed in 2017–2020.
- The database includes test results for long-term oven aged specimens; including those for the eleven 2019 shadow projects and all of the 2020 projects, which were all shadow tested.

IDOT's I-FIT benchmarking has been used to create a database with over 3,000 test sets that has resulted in valuable analyses to understand the materials sensitivity of the test.

IDOT updates the analyses of test results on a regular basis. The following factors are studied in the I-FIT database analysis: test specimen air voids content; specimen type: laboratory-produced, plant-produced, field cores; polymer-modification of binder and grade; virgin binder low temperature PG; RBR; total binder content; virgin binder content; design VMA; test specimen VMA; NMAS; and volume of effective binder.

For example, the database analyses reveal that an increase in FI value is observed with a lower low temperature PG, an increase in design VMA, and an increase in total or virgin binder content. On the other hand, a reduction in FI value was observed with the increase in RBR.

The databases of HWTT and I-FIT test results are also used to refine and revise the performance test methods and their associated criteria as deemed necessary. IDOT will continue to populate performance test results into its databases. The sensitivity of performance tests to material properties will continue to be evaluated with the inclusion of new asphalt mixture test results, which will help in refining specifications and guidelines to design asphalt mixtures with satisfactory cracking resistance.

Conducting Shadow Projects. Shadow I-FIT testing was conducted in 2019 and 2020 during which IDOT did not require contractors to meet any limits for FI during production. The aims of the shadow projects were two-fold: 1) to work out asphalt mix design criteria, sampling, and testing logistics; and 2) to validate the established threshold criteria for I-FIT test parameter in particular. The shadow projects facilitated the buy-in from the industry.

Shadow projects were an important part of the implementation plan.

In 2019, in addition to the 29 I-FIT projects (with short-term aging FI requirements) there was at least one I-FIT shadow project per district conducted for a total of 10 shadow projects statewide. These shadow projects did not have I-FIT requirements in place but did involve daily testing for I-FIT at short-term and long-term oven aging conditions (surface asphalt mixtures only) as well as daily testing for inline binder samples for ΔT_c at two PAV cycles (i.e., 40 hours). The following were the goals of the I-FIT shadow projects:

- Allow districts to gain experience with I-FIT after long-term oven aging of plant-produced asphalt mixtures.
- Quantify the daily variation in production FI of asphalt mixtures.
- Determine whether a minimum FI of 4.0 for long-term oven aged plant-produced asphalt mixtures can be met.
- Determine whether the production FI for long-term oven aged plant-produced asphalt mixtures is driven by plant conditions or binder source.

The original plan was a full implementation of I-FIT in 2020 that was postponed by IDOT after discussion with industry in order for contractors to gain more experience and become reasonably comfortable with the performance test. Thus, IDOT conducted district shadow testing on all asphalt projects including the short-term and long-term oven aging conditions (surface asphalt mixtures only) for the I-FIT. The following summarizes the most relevant feedback comments received from the various IDOT districts on shadow performance testing in 2020:

- Completing the I-FIT performance testing in less than three weeks is generally not an issue. All I-FITs have generally been done within three days to a week of the first day of asphalt mixture production.
- Similar to what it is done with HWTT, prioritization is needed in order to get the I-FIT completed within two days or sooner if it is implemented in the specification. More days are needed to complete testing for long-term oven aged specimens that need three days (72 hours) of oven aging.

- Having an oven solely dedicated to I-FIT specimens would accelerate the turnaround time for test results. In some other instances, having another water bath with scale and another HWTT device would be needed if the volume of testing is to increase. The long-term oven aging for I-FIT in particular puts a strain on the water bath and oven space when having multiple plate samples and an abundance of cores to run from concurrent routine volumetric quality assurance testing.
- Having a full-time technician tasked to the performance testing is likely needed.
- In the case of I-FIT long-term oven aging, samples needed to be prepared on a Monday or a Tuesday. If not, technicians had to wait until Friday to get the I-FIT samples in the oven for long-term oven aging of 72 hours at 95°C. This can delay the results.
- Dealing with more than one project at a time can cause some challenges in meeting a quick turnaround time.
- Getting the samples from the contractor in a timely manner is critical for a quick turnaround. Contractors need to drop off the gyratory bricks for HWTT and I-FIT to the district laboratory as soon as the day following the first day of production.
- Having an initial performance test failure raises a time challenge as the district would need to wait for the asphalt mixture adjustment to perform a re-verification test.
- In one of the districts, utilizing a satellite laboratory for the district field staff to assist in running cores took the pressure off the laboratory staff and allowed for the completion of performance testing.

Meeting the air voids tolerances on I-FIT specimens can add to the challenge in having a quick turnaround time. I-FIT specimens can be out of tolerance on air voids after spending the time to cut and prepare the samples. Thus, requiring the district to request another sample and repeat the entire preparation process. This has been lately addressed by specifying higher air voids on the gyratory cylinders with a tighter tolerance assuming that air voids decrease with test specimen preparation.

Analyzing Production Data. Based on the various shadow and pilot projects completed thus far, reduction in FI values were generally observed for PPLC mixtures compared to LPLC mixtures. The following possible causes for the production-induced reduction in FI values were identified:

- Cold/wet aggregates, RAP, and RAS stockpiles.
- High asphalt mixture production temperatures.
- Extended silo storage time.
- Long haul time.
- Lower binder content from design.
- Increased dust content.
- Time/temperature of binder storage.

Results from PPLC and LPLC mixtures were different; and potential causes were identified.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. Based on a contractor experience with shadow and pilot projects thus far, it was observed that changes to asphalt mixtures to get acceptable performance testing values were material specific. This also has been observed by IDOT with their large database of test results from benchmarking studies. In particular, the performance test results were found to be sensitive to the aggregate type and

properties (e.g., specific gravities, absorptions, particle shapes), binder content, etc. Contractors had to adjust bin percentages or use different aggregate sources to get passing performance test results.

Nonetheless, contractors sometimes struggled with the changes needed to get acceptable results in performance tests. Several asphalt mixtures were failing the FI criteria. Contractors needed more flexibility in using additives and modifiers in order to produce asphalt mixtures that are in compliance with specifications. Furthermore, it was more challenging for contractors to meet performance test criteria on plant-produced asphalt mixtures rather than for laboratory-produced asphalt mixtures during the design stage.

Task 6: Specifications and Program Development.

Conducting Pilot Projects. IDOT originally introduced the HWTT into routine asphalt mix designs in 2012 in order to minimize the risk of designing mixtures that are prone to rutting and stripping. This was done in partnership with the industry following the purchase of equipment in 2010 and the use of HWTT on pilot projects throughout the State.

In creating the timeline, IDOT generally chose to advance BMD annually. Each year they advanced accordingly with the general plan: one pilot project per district, two pilot projects per district, interstates and statewide implementation. In 2016, IDOT

Pilot projects were introduced gradually and started with one per district.

planned for 1 pilot project per each of the 9 districts. This resulted in a total of 11 I-FIT pilot projects that were conducted statewide (Districts 1 and 5 conducted two pilot projects each). Laboratory compacted specimens were tested during asphalt mix design and production. Field cores were sampled and tested immediately after construction. Subsequent field cores are taken annually and tested as well to help determine the rate that the FI is reduced after time in-place on the roadway. Pavement distress monitoring was conducted before construction and is being conducted every year since construction.

In 2017, IDOT planned for two I-FIT projects per district. This resulted in a total of 16 statewide. Laboratory compacted specimens were tested during asphalt mix design and production. IDOT initiated the ICT R27-175 research study for the development of a long-term aging protocol for the implementation of the I-FIT. In 2018, IDOT increased the number of I-FIT projects to a total of 32 projects statewide.

Since the start of pilot projects in 2016, IDOT offered the contractors to have their asphalt mixtures tested for I-FIT. Test results were shared with the contractors, thus providing them with the opportunity to gain trust and comfort with the I-FIT. Select contractors took IDOT up on the offer and sent their asphalt mixtures to IDOT for testing. With time, fewer asphalt mixtures were sent by contractors to IDOT for testing. It should be noted that contractors had to send IDOT all asphalt mixtures for shadow testing on all projects constructed in 2020. Several contractors and other private laboratories purchased I-FIT and/or HWTT machines and are conducting their own testing to better learn the performance characteristics of their asphalt mixtures.

Final Analysis and Specification Revisions. According to the special provision HOT-MIX ASPHALT – MIXTURE DESIGN VERIFICATION AND PRODUCTION (MODIFIED FOR I-FIT) (BDE) (effective January 2, 2021) performance testing during production is to be conducted according to the following IDOT requirements.⁽²⁴⁾ The asphalt mixture is required to meet the performance tests criterion for TSR, HWTT, and I-FIT. The start of asphalt mixture production and JMF adjustments can only initiate after the JMF has been approved as summarized in figure 9.

The specification addresses performance testing during mix design and production.

In the case of High ESAL mixtures, a test strip is completed at the beginning of production for each asphalt mixture according to the Manual of Test Procedures for Materials “Hot Mix Asphalt Test Strip Procedures.” A test strip is not needed for shoulder applications or asphalt mixtures with a quantity less than 3,000 tons; however, such mixtures are still sampled on the first day of production for the HWTT and I-FIT testing.

Before constructing the test strip, target values are determined by applying gradation correction factors to the JMF when applicable. The JMF becomes the adjusted JMF (AJMF) upon completion of the first acceptable test strip. The asphalt mixture placed during the initial test strip is removed and replaced if determined to be unacceptable to remain in place.

Asphalt mixture representing the test strip is sampled, prepared/compacted, and delivered by the contractor within two working days after sampling to IDOT district laboratory for HWTT and I-FIT verification testing. IDOT requires the HWTT and I-FIT results to meet performance tests criteria (table 11). Upon notification by IDOT of a failing HWTT and I-FIT and prior to restarting production, the contractor should make necessary adjustments to the mixture production and submit another mixture sample for IDOT to conduct I-FIT and HWTT. Upon consecutive failing HWTT and I-FIT, no additional mixture is produced until passing the performance tests criteria. IDOT may conduct additional HWTT and I-FIT on production asphalt mixtures.

In the case of Low ESAL mixtures (excluding Class D patches, pavement patching and incidental asphalt mixture), I-FIT testing will be performed during asphalt mixture production. The contractor will sample and deliver prepared samples to the IDOT district laboratory for I-FIT verification testing.

In 2021, Contractors will compact 160 mm gyratory cylinders to 7.5 ± 0.5 percent air voids. Districts then verify the gyratory cylinder air voids and prepare the HWTT and I-FIT specimens.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. IDOT requires all technicians to be trained and certified through the IDOT Quality Management Training Program that is managed and provided by Lake Land College.⁽²⁵⁾ All three IDOT Asphalt Quality Management Programs require that industry be responsible for sampling, testing and documenting for specification compliance (QC), and IDOT be responsible for random monitoring testing and acceptance testing. The purpose of the training and certification

Performance tests are part of the standard technician certification program.

program is to develop and maintain a pool of well-trained asphalt specialists for the State and contractors to design, test, and manage asphalt pavements. Training of both industry and IDOT employees is an integral part of this quality management program.

The IDOT Quality Management Training Program provides five training courses in testing and evaluating asphalt mixtures and aggregates. The training includes two courses on aggregates and three on asphalt mixtures.⁽²⁵⁾ The courses are revised regularly to include updated and new test methods. Individuals must pass both a written and a laboratory proficiency examination for the one of the two aggregate courses and the first of three HMA courses and a written examination for the last two HMA courses.

The Illinois-modified AASHTO T 324 (HWTT), Illinois-modified AASHTO TP 124 (I-FIT), and Illinois-modified AASHTO T 283 (TS) are covered under the *CET 029 Hot Mix Asphalt Level I* training course and certification. This is a 5-day training course that covers laboratory testing of asphalt mixtures using Superpave technology and information on mixture production. The successful completion of this course permits an individual to do the testing associated with contracts let under IDOT's Quality Management Programs.

Course manuals designed for understanding the testing requirements of IDOT are made available to participants.⁽²⁶⁾ The course manuals are updated regularly and comprise detailed descriptions and photos of test methods including: equipment, sampling, specimen preparation, test procedure, etc. Instructional videos are also shared with the participants. The videos have been very effective and well accepted by participants. IDOT requires individuals to be certified once. Efforts are underway between IDOT, industry, and Lake Land College to develop re-certification requirements.

Task 8: Initial Implementation.

In 2019, IDOT implemented I-FIT on all interstate projects with additional projects approved by Central Office for a total of 29 projects statewide. In 2020, the original plan was a full

IDOT's implementation plan was very systematic.

Implementation of I-FIT that was postponed by IDOT in order for contractors to gain more experience and become reasonably comfortable with the performance test. In 2021, IDOT implemented I-FIT thresholds in design and production for short-term aged specimens (including higher thresholds for SMA and IL-4.75 mixtures). In 2022, IDOT fully implemented I-FIT thresholds in design and production for short-term and long-term aged specimens.

IDOT plans to begin allowing terminally blended binder modifiers in non-polymer modified binders in conjunction with new binder performance testing protocol in January of 2023.

Based on a contractor experience with shadow and pilot projects thus far, the following observations were made:

- The variability associated with I-FIT can be challenging, especially when comparing test results obtained from two separate laboratories. However, this is not currently a major issue as all asphalt mixtures are being approved based on performance tests that are being conducted by IDOT.

- Many contractors chose to invest in equipment, especially those operating in remote areas with limited or no services from consultants. Some contractors partnered in equipment purchasing and ownership.
- Laboratory workspace can be challenging. This required one contractor to convert a storage room into a temperature-controlled room that houses performance testing equipment. In one instance, the contractor had to acquire interchangeable table jigs due to space limitation.
- IDOT’s support in testing and sharing test results with contractors for asphalt mixtures during pilot projects was very helpful. Contractors were able to gain comfort and trust with performance testing and learn how it impacts their own asphalt mix designs and production.
- Contractors in Illinois have challenges in acquiring qualified technicians and having to run performance tests added to that challenge as they require additional training on equipment and test result calculations.
- No issues or challenges in meeting in-place density requirements were observed or encountered.
- The partnership and continuous discussion between IDOT, industry, IAPA, and universities is key for a successful implementation of performance tests for design and production of asphalt mixtures.

OBSERVED BENEFITS

The use of BMD on test field projects allowed contractors to optimize the use of recycled materials and still be able to produce asphalt mixtures that are in compliance with IDOT specifications. The traditional volumetric-based mix design did not provide optimum performance for asphalt mixtures with higher recycled materials content. In general, no problems were encountered with constructing asphalt pavements using a BMD mixture.

The personal testimonial from IDOT District 6 was a powerful way to document benefits.

District 6, for example, benefited from the implementation of performance testing. Occasional permanent deformation and frequent tender asphalt mixtures were a recurring problem, especially, for High ESAL asphalt mixtures that used natural sand (rounded particles) with higher traffic loading. The district attempted to reduce the use of natural sand in their asphalt mixtures by artificially increasing the N_{design} for High ESAL mixtures at a lower traffic threshold than IDOT policy allowed. With the implementation of HWTT, High ESAL mixtures designed at 50 gyrations, in particular, failed the performance test criteria. This forced the district to delay the implementation of the HWTT for asphalt mixtures designed at 50 gyrations. “I initially opposed the implementation of HWTT with most of our asphalt mixtures in the western part of the district failing the test criteria,” said Greg Heckel, District 6 Materials Engineer. “The HWTT limited the use of several of the aggregate sources commonly available in District 6, thus raising a concern with the ability of contractors to produce an acceptable and economical asphalt mixture for lower traffic loading conditions,” said Heckel. Accordingly, District 6 provided the contractors a 2-year stepped implementation process with targets for each Superpave gyration level before fully implementing the HWTT as part of mix design and production. “After contractors were able to figure out the changes needed to pass our performance test criteria, we

got rid of tender asphalt mixtures and now have a very stable mixture with a much better field pavement performance at lower gyrations,” commented Heckel; “contractors had to reduce the natural sand, increase the design VMA, and use more of the angular fine aggregates in their asphalt mixtures.” A tender asphalt mixture refers to a mixture that is difficult to compact with a tendency to shove under the roller wheels and/or leave longitudinal cracks at the edge of the steel drums. This is mainly caused by a lack of friction between aggregate particles or a lack of shear strength in the asphalt mixture.

Based on his past experience with HWTT and the observed benefits from its implementation, Heckel is fully supporting the implementation of I-FIT in design and production to complement the HWTT. “This will allow us to balance the asphalt mixture performance in terms of cracking and permanent deformation while giving contractors flexibility in selecting component materials,” concluded Heckel. Adjustments to the asphalt mixtures made to pass the HWTT resulted in better quality aggregates, aggregate structure and VMA. As a result, the I-FIT results have been passing in District 6.

FUTURE DIRECTION

In 2021, all High ESAL asphalt mixtures (i.e., greater than 30 design gyrations) will be required by IDOT to meet HWTT, I-FIT (short-term aging), and TSR criteria. Furthermore, all Low ESAL asphalt mixtures (excluding Class D patches, pavement patching, and incidental asphalt mixtures) will be required to meet I-FIT criteria by IDOT. IDOT will also begin conducting a binder performance test in 2022 to coincide with the allowance of terminally blended modifiers (non-polymer modified binders only). In terms of training, IDOT is in discussions to develop a re-certification process for all IDOT quality management training program courses.

IDOT has recently completed a project and has three active research studies:

- ICT R27-196 *Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements* (2018–2021)
- ICT R27-204 *Optimized Hot-Mix Asphalt (HMA) Lift Configuration for Performance* (2019-2023)
- ICT R27-216 *Optimizing the Use of Local Aggregates in Stone-matrix Asphalt (SMA)* (2020–2023)
- ICT R27-233 *Mechanistic-Empirical Design Procedures for Flexible Pavements* (2021-2024)

The full implementation effort needs to be supplemented with proper communication, training, and education activities. Contractors will need to be educated on what changes can be made to the asphalt mixture composition or proportions in order to make informed and cost-effective decisions to improve performance and meet applicable specification limits. In 2022, IDOT excluded from the standard specifications the VFA range requirements.⁽²¹⁾ Work will continue on the process of having “Perpetual Mix Designs” that can be approved indefinitely.

CHAPTER 4 VIRTUAL SITE VISIT: LADOTD (AUGUST 2020)

INTRODUCTION

In fiscal year 2018–2019, LaDOTD placed about 1.63 million tons of asphalt mixture (table 17). The LaDOTD standard asphalt mixtures are specified in the 2016 standard specifications (amended in 2018) *Section 501 Thin Asphalt Concrete Applications* and *Section 502 Asphalt Concrete Applications*.^(28,29) The LaDOTD asphalt mixture types and applications are summarized in table 18.

The Section 501 of specifications applies to all thin lift asphalt mixtures that are used as a finish course with a typical thickness of 0.75–1.5 inches. These include: “Dense Mix” applied on traffic volumes less than 3,500 average daily traffic (ADT); and “Coarse Mix” or open graded friction course (OGFC) applied to all traffic volumes.

Table 17. LaDOTD Asphalt Mixture Quantities.

Fiscal Years	16–17	17–18	18–19
Asphalt Mixture Tonnage	1,443,153	1,382,751	1,632,735
Number of Projects	313	203	288

Table 18. Asphalt Mixture Types Used by LaDOTD.

Specifications	Mixture Types	Applications	
		New and Rehabilitation	Finished Course
Thin Asphalt Concrete Applications (Section 501)	Dense Mix	Traffic volumes less than 3,500 ADT.	Thin lift asphalt mixture placed over a Section 502 asphalt mixture pavement of a PCC pavement
	Coarse Mix	All traffic volumes. Can be substituted in place of Dense Mix without change order.	Thin lift asphalt mixture placed over a Section 502 asphalt mixture pavement or a PCC pavement
	OGFC	All traffic volumes, typically specified for use on Interstate Highway System. Can be substituted in place of Coarse Mix or Dense Mix applications without change order.	Thin lift asphalt mixture placed over a Section 502 asphalt mixture pavement or a PCC pavement
Asphalt Concrete Mixtures (Section 502)	Wearing Course	Final lift placed, all traffic volumes.	–
	Binder Course	Lift placed prior to the final lift, all traffic volumes.	–
	Base Course	All traffic volumes	–
	SMA	Wearing course for high traffic applications (rut resistance asphalt mixture). Specified on all interstate wearing courses with traffic volumes greater than 35,000 ADT.	–

–indicates not applicable.

The Section 502 of specifications applies to wearing, binder, and base courses including SMA. The wearing course is defined as the final lift placed while the binder course is defined as the lift placed prior to the final lift. Mainline asphalt mixtures include wearing, binder, and base courses for travel lane, ramps and turnouts greater than 300 ft, interstate acceleration/deceleration lanes, turn lanes, and the two center lanes for airports. SMA is a plant-produced asphalt mixture wearing course that is rut resistant for high traffic applications. Minor asphalt mixtures include those used for bike paths, detour roads, joint repair, leveling, shoulders, patching, etc.

In general, the primary differences in specifications are Section 501 asphalt mixtures have a higher design air voids requirements with no minimum requirements either for VMA or critical strain energy release rate (J_c) as measured using the semi-circular bend (SCB).

LaDOTD specifications for asphalt mixtures currently require the HWTT (AASHTO T 324) for rutting performance evaluation (Section 501 and Section 502 asphalt mixtures) and the SCB test (ASTM D8044) for cracking performance evaluation (Section 502 asphalt mixtures only).

With the significant increase in traffic volume on highways, LaDOTD observed that asphalt pavements built with acceptable levels of quality according to specifications have started to experience more frequent premature failures or reduced performance. Furthermore, the increase interest in using rubber-modified binders, RAP, and WMA technologies made it challenging for LaDOTD to adequately assure the long-term performance of asphalt pavements with its conventional acceptance practice that is mainly based on asphalt mixture volumetric properties (e.g., VMA, air voids) and surface roughness. LaDOTD specifications resulted in stiff and dry asphalt mixtures that were prone to early cracking and durability problems. Accordingly, LaDOTD started to examine the use of performance tests and the BMD on all of its asphalt mixtures.

The “why” was to address premature failures and allow the use of innovative and recycled materials.

Overall, LaDOTD employed a phased-in approach for implementation of BMD. The Louisiana Transportation Research Center (LTRC) initiated several research studies in 2011 to develop performance specifications for asphalt mixtures used in Louisiana. The results and findings from these studies were implemented in the *PART V—ASPHALT PAVEMENTS* of the *2016 Standard Specifications for Roads and Bridges*, which was also amended in 2018.⁽²⁹⁾ The HWTT and SCB performance tests were implemented to assess the stability and durability of asphalt mixtures during the design and acceptance process.

BMD APPROACH

Figure 11 shows a flowchart of the overall BMD for *Section 502 Asphalt Concrete Mixtures* that highlights the major steps for undertaking a mix design according to LaDOTD specifications (2018 amendments). The LaDOTD requirements for binder PG, volumetric design, and performance testing for Sections 501 and 502 asphalt mixtures are summarized in table 19 to table 21. Performance testing specifications are provided as a function of traffic condition as well as asphalt mixture type and location within the asphalt pavement structure. LaDOTD bans the use of RAS in any of its asphalt mixtures.

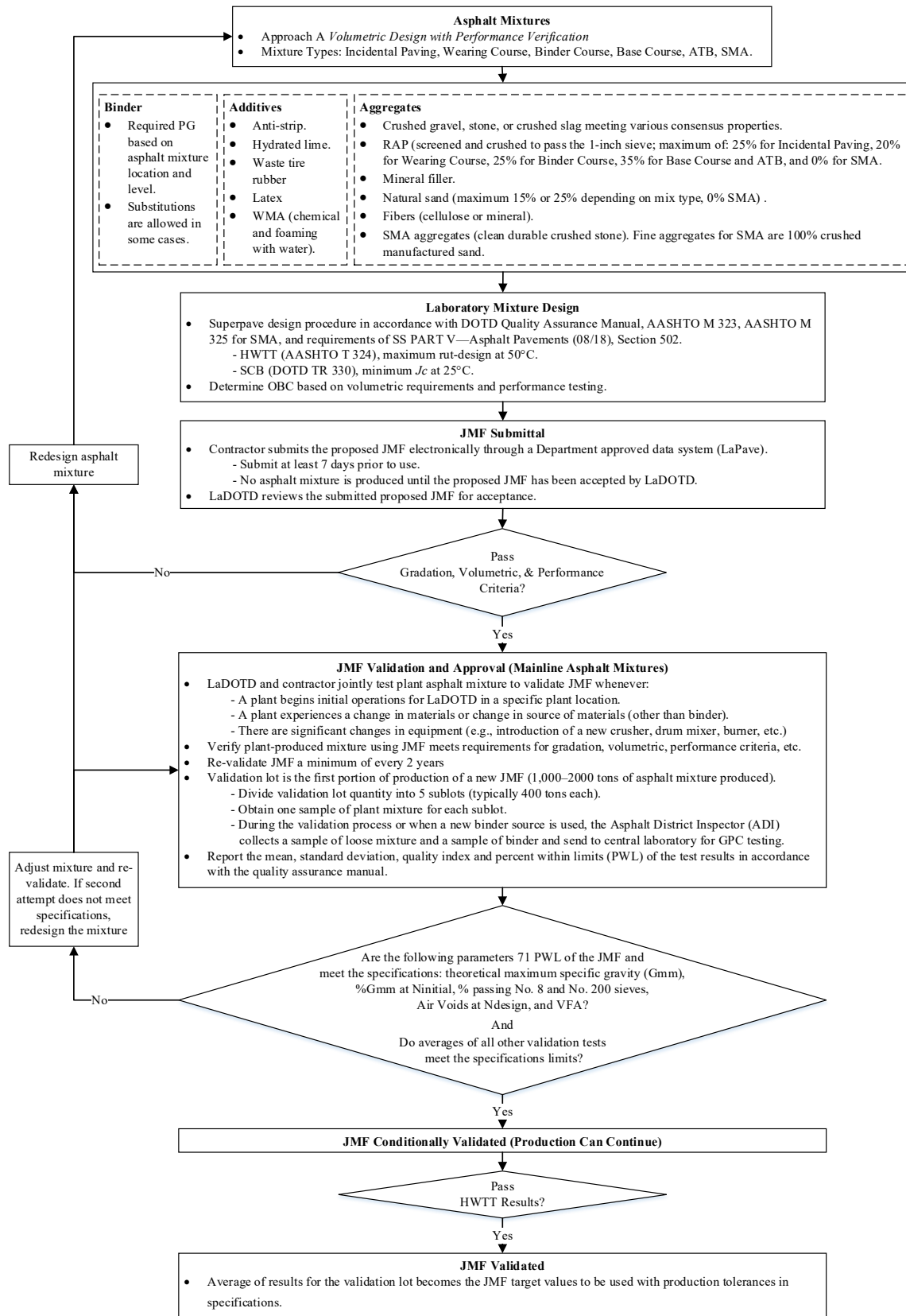


Figure 11. Chart. Overview of LaDOTD’s BMD process (Section 502—2018 amendments).

Table 19. LaDOTD Specifications for Binder PG.

Specifications	Mixture Type	Specified Binder PG*	Substitutions Allowed	
			Lower Grade	Higher Grade
Section 501	Dense Mix	PG 70-22	–	–
	Coarse Mix	PG 70-22m	–	–
	OGFC	PG 76-22m	–	–
Section 502	Mainline Wearing and Binder Course; Level 1	PG 70-22m	PG 67-22 with traffic volume < 3,500 ADT	PG 76-22m PG 76-22rm
	Mainline Wearing and Binder Course; Level 2	PG 76-22rm PG 76-22m	PG 70-22m with hydrated lime	
	SMA	PG 76-22rm PG 76-22m	–	–
	Base Course; Level 1	PG 67-22	PG 58-28 (specified when more than 25% RAP is used)	PG 76-22m PG 76-22rm PG 70-22m
	Minor Mixes Including Leveling; All levels	PG 67-22	–	PG 76-22m PG 76-22rm PG 70-22m

–Not applicable.

*m=modified; rm=rubber modified.

Table 20. LaDOTD Specifications for Mix Design Volumetric Properties.

Specifications	Mixture Type	N_{design}	Binder Content (%)	Design Air Voids (%) [*]	VFA (%)	VMA (Minimum %)					Dust-to-Binder Ratio	Drain-down (%) [#]
						NMAS (mm)						
						37.5	25	19	12.5	9.5		
Section 501	Dense Mix	50	≥ 4.5	4–6	–	–	–	–	–	–	0.6–1.6	–
	Coarse Mix	75	≥ 4.5	6–8	–	–	–	–	–	–	–	≤ 0.15
	OGFC	50	≥ 6.5	18–24	–	–	–	–	–	–	–	≤ 0.30
Section 502	Incidental Paving	55	–	2.5–4.5	–	–	–	–	13.5	–	0.6–1.6	–
	Wearing Course; Level 1	55	–	2.5–4.5	69–80 [§]	–	–	–	13.5	–	0.6–1.6	–
	Wearing Course; Level 2	65	–	2.5–4.5	69–80 [§]	–	–	12.5	13.5	–	0.6–1.6	–
	Binder Course; Level 1	55	–	2.5–4.5	69–80 [§]	–	11.5	12.5	–	–	0.6–1.6	–
	Binder Course; Level 2	65	–	2.5–4.5	69–80 [§]	–	11.5	12.5	–	–	0.6–1.6	–
	Base Course; Level 1	55	–	2.5–4.5	69–80 [§]	10.5	11.5	–	–	–	0.6–1.6	–
	Asphalt Treated Base (ATB); Level 1	30	≥ 3.0	2.5–4.5	–	–	–	–	–	–	0.6–1.6	–
	SMA	65	≥ 6.0	2.5–4.5	≥ 69	–	–	–	16.0	–	0.6–1.6	–
Section 502 (< 1,000 ADT)	Incidental Paving	40	–	2.5–4.5	–	–	–	–	14.0	15.0	–	–
	Wearing Course	40	– [§]	2.5–4.5	72–80 [§]	–	–	–	14.0	15.0	–	–

–Not applicable.

[#]ASTM D6390.

^{*}Design target voids at mid-point of void specification. Full range allowed for OGFC.

[§]Mix design minimum VFA is 72.0%, Mix design minimum VFA for PG76-22rm is 75.0%, and 71% for 25 mm NMAS mixtures.

Table 21. LaDOTD Specifications for Mix Design Performance Testing.

Specifications	Mixture Type	HWTT @ 50°C*		SCB, J_c @ 25°C (KJ/m ²)
		maximum rut depth (mm)	Number of Wheel Passes	
Section 501	Dense Mix	≤ 12 mm	12,000	–
	Coarse Mix	≤ 12 mm	20,000	–
	OGFC	≤ 12 mm	5,000	–
Section 502	Incidental Paving	≤ 10 mm	10,000	–
	Wearing Course; Level 1	≤ 10 mm	20,000	≥ 0.5
	Wearing Course; Level 2	≤ 6 mm	10,000	≥ 0.6
	Binder Course; Level 1	≤ 10 mm	20,000	≥ 0.5
	Binder Course; Level 2	≤ 6 mm	20,000	≥ 0.6
	Base Course; Level 1	≤ 12 mm	20,000	–
	ATB; Level 1	≤ 10 mm	10,000	–
	SMA	≤ 6 mm	20,000	≥ 0.6
Section 502 (< 1,000 ADT)	Incidental Paving	≤ 10 mm	10,000	–
	Wearing Course	≤ 10 mm	15,000	≥ 0.5

–indicates not applicable.

*Compact HWTT specimens to the mid-point of specified design void; OGFC to 18% air voids.

The LaDOTD’s BMD for designing asphalt mixtures and approving JMFs follows *Approach A–Volumetric Design with Performance Verification*. Depending on the asphalt mixture type, Section 501 asphalt mixtures are designed at 50 or 75 gyrations (N_{design}) to design target air voids of 5 percent for Dense Mix, 7 percent for Coarse Mix, and 18–24 percent for OGFC. Section 502 asphalt mixtures are designed at 30 to 65 gyrations to a design target air voids of 3.5 percent.

The contractor submits the proposed JMF electronically through LaPave online at least 7 days prior to use for review and approval by LaDOTD.⁽³⁰⁾ At a minimum, the JMF must include the recommended materials proportions, extracted gradation, recommended mixing and compaction temperatures, and supporting design data. Asphalt mixture is not be produced until the proposed JMF has been accepted.

Once accepted, LaDOTD and the contractor validate the JMF by jointly testing the plant-produced asphalt mixture, which has to meet all LaDOTD’s requirements including aggregate properties and gradation, volumetric properties, and performance tests criteria. It should be noted that a JMF for a mainline asphalt mixture is validated whenever an asphalt plant begins initial operations for LaDOTD in a specific plant location; whenever a plant experiences a change in materials or change in source of materials (other than binder source); or when there are significant changes in equipment, such as the introduction of a new crusher, drum mixer, burner, foaming device, etc. All JMFs are re-validated a minimum of every 2 years (re-validation may consist of reviewing ongoing production data). JMF’s for minor mixtures do not require validation; however, the first five QC sublots are used to establish targets for production tolerances.

The validation lot is the first portion of production of a new JMF and consists of 1,000–2,000 tons of asphalt mixture produced. The asphalt mixture quantity for the validation lot is divided into 5 sublots with one sample of plant-produced asphalt mixture is obtained for each subplot. During the validation process or when a new binder source is used, the Asphalt District Inspector

(ADI) will collect a sample of loose plant-produced asphalt mixture and a sample of binder that will be sent to the LaDOTD central materials laboratory for gel permeation chromatography (GPC) testing.

The JMF is considered conditionally validated if the following parameters are 71 percent within limits (PWL) of the JMF and meet the specifications: theoretical maximum specific gravity (Gmm), percent Gmm at $N_{initial}$, percent passing the No. 8 and No. 200 sieves, percent air voids at N_{design} , and VFA. The averages of all other validation tests, including SCB test results (Jc), shall meet the related specifications limits. The production can continue during conditional validation (i.e., while waiting for the HWTT results). The JMF is considered validated by LaDOTD with passing HWTT results.

If any parameter falls below 71 PWL or the validation average falls outside of specifications, the asphalt mixture needs to be adjusted and revalidated. The asphalt mixture needs to be redesigned by the contractor if it failed to meet specifications after the second attempt. Upon validation of the JMF, the average of the results for the validation lot becomes the JMF target values to be used with the acceptable production tolerances.

In comparison to AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design” and AASHTO R 35, “Standard Practice for Superpave Volumetric Design for Asphalt Mixtures,” the following key modifications are implemented by LaDOTD to their volumetric design criteria (table 20 and table 22):

- Specified 30 to 75 gyrations for design and acceptance of all asphalt mixtures.
- Specified a minimum binder content for thin asphalt mixtures (Dense Mix, Coarse Mix, and OGFC), ATB Level 1, and SMA. In order to avoid bleeding of the asphalt mixture a draindown is also specified for Coarse Mix and OGFC.
- Increased target design air voids at N_{design} for thin asphalt mixtures. On the other hand, reduced target design air voids by 0.5 percent for all other asphalt mixtures.
- Whenever specified, VMA requirements were lower by 0.5 percent than the respective requirements in AASHTO M 323 for Superpave asphalt mixtures. Nonetheless, these VMA requirements are higher by 0.5 percent than what was specified by LaDOTD prior to the 2016 standard specifications. This increase in VMA was introduced to increase the durability of asphalt mixtures by allowing more binder into the mixture.
- Except for Section 501 and Section 502 Incidental Paving, increased the lower and upper limits of VFA for all asphalt mixtures.
- Increased the upper limit of the dust-to-binder ratio requirement by 0.4 percent and excluded requirement for asphalt mixtures on low volume roads (< 1,000 ADT).
- Increased the maximum allowable RAP by 5 percent for all mixtures relative to the maximum RAP percentage specified in the 2016 standard specifications.

Table 22. Summary of LaDOTD Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Mixture Type								
	Section 501		Section 502					Section 502 (< 1,000 ADT)	
	Dense Mix	Coarse Mix and OGFC	Incidental Paving	Wearing and Binder Courses	Base Course; Level 1	ATB; Level 1	SMA	Incidental Paving	Wearing Course
N_{design}	↓	↓	↓	↓	↓	↓	↓	↓	↓
Density at N_{design}	↓	↓	↑	↑	↑	↑	↑	↓	↓
Density at N_{max}	↔	↔	↔	↔	↔	↔	↔	↔	↔
Design Binder Content	Min	Min	–	–	–	Min	Min	–	–
VMA	–	–	↓	↓	↓	↓	↑	↔	↔
VFA	–	–	–	↑	↑	–	↑ LL	–	↑ LL
Dust-to-binder ratio	↑ UL	–	↑ UL	↑ UL	↑ UL	↑ UL	↑ UL	–	–
Natural Sands	Max	–	–	Max	Max	Max	Max	–	Max
Draindown (%)	–	Max	–	–	–	–	–	–	–
HWTT Rut Depth at Specified Wheel Passes	Max	Max	Max	Max	Max	Max	Max	Max	Max
SCB, J_c	–	–	–	Min	–	–	Min	–	Min

–indicates not applicable or not specified; Min=minimum; Max=maximum; R=report only; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit, ↑ LL=increased lower limit.

IMPLEMENTATION PROCESS OF BMD

The following section summarizes LaDOTD’s experience with BMD implementation in terms of the eight tasks identified in figure 2. As noted before, the tasks organize the various activities involved in the implementation of a BMD program that a State DOT can consider as part of its own effort to putting BMD into practice.

Task 1: Motivations and Benefits of BMD.

The motivations for implementation of BMD in LaDOTD were primarily two-fold: 1) there was an immediate need to address the observed frequent premature failures of asphalt pavements as a result of significant increase in traffic volume; and 2) there was a desire for a responsible use of innovative and recycled materials (e.g., rubber-modified binders, RAP) to improve asphalt pavement performance. The original LaDOTD specifications resulted in stiff and dry asphalt mixtures that were prone to early cracking and durability problems.

Assuring long-term performance of asphalt pavements using innovative and recycled materials is challenging with a conventional acceptance practice that is mainly based on asphalt mixture volumetric properties. Thus, LaDOTD recognized the potential benefits with the implementation of performance tests to balance the stability/rutting and cracking/durability performance of asphalt mixtures.

Task 2: Overall Planning.

Identification of Champions. State DOT champions were committed to implementing the BMD program and provided leadership for the various implementation activities. Thus, LaDOTD has been leading and investing significantly in the process to develop and implement BMD for all of its asphalt mixtures. Contractors were also generally supportive of the BMD approach.

LaDOTD communicated with stakeholders the need and the anticipated enhancements in the quality of asphalt mixtures by having a BMD for design and acceptance. This helped LaDOTD in securing the necessary management support and commitment from the State DOT throughout the BMD implementation process to fund pertinent activities such as research, equipment purchasing, pilot projects, training and certification programs, etc.

Establishing a Stakeholders Partnership. While an official joint task force with industry and academia was not established, LaDOTD kept the industry involved during the process through continuous communications and discussions about forthcoming specification changes, and the opportunity to provide comments and inputs on any suggested changes. For instance, one of the suggested changes by the industry that was considered in the revised specifications is the use of the same size for compacted HWTT and SCB specimens (samples were initially compacted to different heights). LaDOTD has also an established partnership with academia through LTRC to help in supporting critical and pressing research needed as part of the development and implementation of BMD.

Partnership with LTRC was a key.

Doing Your Homework (Identifying the Issues, Identifying Resources, and Reviewing Literature). LaDOTD main issues with their asphalt mixtures was stability/rutting and cracking/durability performance. LTRC has a long history of using the HWTT (since early 2000) and SCB (since 2002) for forensic evaluation or as a research tool for screening of asphalt mixtures with good and poor rutting and cracking resistance potential, respectively. LaDOTD also relied on the fact that several State DOTs have successfully used or implemented (e.g., 2004 TxDOT specifications) a version of the HWTT to evaluate rutting potential and moisture susceptibility of their asphalt mixtures.⁽³¹⁾ Prior LTRC research studies also revealed the premises of the SCB test to predict the fracture resistance of asphalt mixtures. The effort to

LaDOTD has a long history with the HWTT (since 2000) and SCB (since 2002).

evaluate the combined use of HWTT and SCB in mix design was initiated in 2011. Accordingly, resources were committed by LaDOTD to fund necessary research studies to develop and implement BMD for its asphalt mixtures.

Establishing Goals. LaDOTD's goal has been the application of the BMD program onto all State projects for asphalt mix design and acceptance.

The goal from the start was to use BMD on all projects for mix design and acceptance.

Identifying Available External Technical Information and Support. LaDOTD has planned and engaged with LTRC to provide information to guide decisions related to implementation of performance tests.

Developing an Implementation Timeline. Several research studies were planned and undertaken to implement BMD into engineering practice. The following summarizes the major steps that were undertaken by LaDOTD to implement BMD into engineering practice:

With the long history of performance testing, BMD implementation was condensed into a few years.

- Build-up experience and establish a large database of performance test results based on forensic investigations and research studies. Funding support for research studies is key for full implementation of BMD.
- Develop necessary pilot specifications for the BMD.
- Carry out a pilot program with field pavement trials. This involves upgrading or acquiring new equipment for performance testing and allocating the necessary budget.
- Make practical adjustments to the test methods (feedback comments were mainly from contractors involved in pilot studies).
- Assure the industry buy-in for the BMD approach for designing and accepting asphalt mixtures before full implementation on all asphalt mixtures produced in the State.
- Provide the necessary training and support to the industry on test methods and data analysis.

As a result, LaDOTD implemented the BMD and performance testing into its 2016 standard specifications which were later revised and amended in 2018.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. Rutting and cracking were the two primary asphalt pavement modes of distress identified by LaDOTD to be considered in the BMD process.

Rutting and cracking were the distresses that needed addressing.

Identifying and Assessing Performance Test Appropriateness. The top three factors for LaDOTD in selecting a performance test were: field validation, material sensitivity, and repeatability.⁽¹⁷⁾ LaDOTD recognizes that field validation and correlation of performance test results with measured field pavement performance data is the basis for the BMD approach. In the selection process, consideration was also given to the capability of the performance test to detect changes in asphalt mixture properties and composition, and to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures (based on historical field performance of asphalt mixtures). For LaDOTD, the test results of local asphalt mixtures should not contradict known and observed field pavement performance. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is also key for successful implementation of specifications.

Other important factors for LaDOTD are sample preparation, equipment cost, and training needs. The duration needed for sample preparation, the low-cost associated with specimen fabrication and testing equipment, as well as the need for more efficient QC during production have been key considerations for LaDOTD in the development of test criteria and implementation of performance tests into specifications. Eliminating the need for highly-trained personnel help to reduce the impact other factors might have on the overall implementation effort of performance tests.

With these factors in mind, LaDOTD developed their own cracking performance test for asphalt mixtures through research with LTRC. In particular, the SCB test was selected for implementation in BMD approach because:

The SCB was fundamentally derived from fracture mechanic principles.

- It is an intermediate temperature test for intermediate temperature fracture that addresses the observed type of cracking in Louisiana asphalt pavements.
- It can be conducted using Superpave gyratory compacted specimens or field core specimens.
- The testing equipment is simple and can be adopted at asphalt plant laboratory.
- LaDOTD has a history of forensic success and field correlation.
- The test is fundamentally derived from fracture mechanics principles and is not simply an index test (go/no-go or pass/fail).
- The test procedure is relatively simple to perform and implement.
- The repeatability of the test results is acceptable with a COV less than 15 percent.

Validating the Performance Tests. In 2019, LaDOTD led a pooled fund project that aimed at providing guidance to State DOTs in the selection of a fatigue/fracture performance test to incorporate during asphalt mix design containing high-RAP and/or RAS materials.⁽³²⁾ The asphalt mixtures from the FHWA ALF experiment at the TFHRC (10 test lanes) were also included in this study. Overall a good correlation was observed between the SCB J_c and the ALF passes to 20 feet of cracking. Furthermore, the fatigue cracking performance model used in AASHTOWare Pavement ME was revised by incorporating the J_c parameter (in addition to the tensile strain and dynamic modulus variables) to represent the asphalt mixture’s resistance to cracking. A good correlation was observed between the ALF measured number of repetitions to fatigue failure and the calculated repetitions using the J_c -based model. The SCB test results were also compared and validated against the flexural beam fatigue and the direct tension cyclic

Validation included the FHWA’s ALF, AASHTOWare Pavement ME, and ongoing monitoring.

fatigue tests. Overall, the findings from the pooled fund study provided LaDOTD with additional confidence with and robust validation of the SCB test and related criteria that were established under the benchmarking study.

LaDOTD continues to validate and refine the performance test criteria with additional field pavement performance data and related laboratory performance test results. This can result in a revised specification for design, QA, and performance test thresholds values.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. The LaDOTD central materials laboratory and each of the nine districts have currently an HWTT device that were all purchased during the pilot study phase of the implementation. LTRC currently has two HWTT devices, and seven devices are owned by contractors around the State.

An HWTT is in each of the districts. The SCB is only at LTRC.

Besides LTRC, none of the LaDOTD central or district laboratories currently has the equipment for conducting the SCB test. LTRC has the capability to run the SCB test on three separate

pieces of equipment. Generally, contractors got their central laboratories setup for SCB testing by acquiring the proper equipment for specimen fabrication (e.g., table saw for notching) and testing (e.g., jig for a loading frame or Marshall press). It should be noted that asphalt mix designs in Louisiana are generally conducted by the contractor supplying the asphalt mixture.

Managing Resources. In general, funding and space resources for acquiring and installing new equipment in laboratories have not been a major issue for LaDOTD. This is primarily due to a strong internal support of the LaDOTD administration throughout the various implementation efforts and activities.

Conducting Initial Training. LTRC offered an “SCB Test Training Workshop” to contractors, LaDOTD, and consultants before the release of the 2016 standard specifications and included the following:

- Changes in the new specifications.
- SCB training: test history, concept and theoretical background, research efforts and justifications for the selection of the test criteria, sample preparation and fabrication, testing, data analysis and reporting.
- Laboratory demonstration of SCB test.
- Open forum discussions.

LTRC prepared an instructional video of over 13 minutes long on SCB that was shared with the attendees of the workshop. The video highlighted the details for sample preparation, specimen fabrication, testing, and data analysis. The video was found extremely helpful by the attendees and other involved personnel in the implementation process of the SCB test.

LTRC hosted a workshop with classroom and lab components.

The LTRC training workshop emphasized the importance of proper sample preparation and fabrication and their influence on SCB test results. It was important to demonstrate for the attendees the test method, equipment used, and the efforts to move the test from a research-oriented test on a costly equipment to a routine test on a relatively low-cost equipment without jeopardizing the accuracy of the test results. The training workshop also highlighted the added time and efforts for designing and testing asphalt mixtures in accordance with the new specifications.

LTRC continued to assist and help with testing, data analysis, and technical review on an as-needed basis. This sometimes involves LTRC visiting the contractor’s laboratory at the asphalt plant to examine and assess with the equipment.

Evaluating Performance Testing. In 2015, LTRC completed the National Cooperative Highway Research Program (NCHRP) Project 20-07/Task 361 Hamburg Wheel-Track Test Equipment

Test results from different equipment manufacturers can produce different results.

Requirements and Improvements to ASHTO T 324. The study evaluated the capability of the HWTT devices available in the U.S. market and identified potential issues with different aspects of AASHTO T 324 standard procedure in order to ensure proper testing and accurate, reproducible results. Accordingly, researchers proposed revisions to AASHTO T 324 enabling the use of a performance type specification for HWTT devices. The main findings were related to the wheel position

waveform, temperature control system, deformation measurements, and data collection and reporting.

LaDOTD is funding a research study to evaluate the SCB test for potential use during production for acceptance by establishing an aging scaling factor to estimate test results for long-term oven aged specimens from those obtained on short-term oven-aged specimens. The current long-term oven aging for SCB specimens is 5 days at 85°C.

Conducting Inter-Laboratory Studies. The AASHTO T 324 and ASTM D8044 performance tests have no information regarding the precision and bias of the test method. This may create a potential issue if two separate laboratories achieve different test results for the same asphalt mixture.

Historically, a COV of less than 20 percent has been observed with the HWTT and SCB results from the same laboratory. Early on in the process the variability of the SCB test results was high (COV of about 30 percent), which triggered a thorough investigation. This high variability in the test results was related to specimen fabrication. Thus, improvements were made and a QC form for specimen fabrication was developed and shared with technicians for employment.

High variability from specimen fabrication resulted in creation of specimen fabrication QC form.

LaDOTD plans on using the test results of the proficiency testing program to establish the variability within each laboratory and between laboratories for the HWTT. All laboratories and technicians involved in testing asphalt mixtures for acceptance are required to participate in the proficiency testing program. LaDOTD envisions the SCB test to be part of the program once the test is implemented for production.

Task 5: Establishing Baseline Data.

Reviewing Historical Data & Information Management System. LaDOTD has a long history of using the HWTT (20 years) and SCB (18 years) for forensic and research evaluation of asphalt mixtures. This long record of test results allowed LaDOTD to tie asphalt mixture properties to their related field performance.

A long history of performance test results was valuable to tie properties to field performance.

LaDOTD development of the initial performance test criteria was undertaken during the development of a framework for the implementation of BMD for Louisiana.⁽³³⁾ A total of 9 field projects across Louisiana were evaluated: 6 existing projects that had 3–8 years of in-service life, and 3 new projects. HWTT and SCB tests were conducted on field core samples to measure the performance indicators for rutting and cracking resistance, respectively.

Statistical and comparative analyses were conducted to identify correlations between field pavement performance and laboratory measured asphalt mixture performance indicators. The Mechanistic-Empirical Pavement Design Guide (MEPDG) projected terminal rutting was the field rutting performance indicator related to HWTT rut depth. On the other hand, the 20-year projected combined cracking indices (alligator cracking index and random cracking index) were

the field cracking performance indicators related to the SCB J_c . The 20-year projected rutting values by the MEPDG simulations were calibrated using field distress data for the selected projects obtained from the Louisiana pavement management system (PMS).

Based on the comparison analyses between the field and laboratory measured performance indicators, initial performance test criteria were established for the HWTT measured rut depths for Level 2 and Level 1 asphalt mixtures in Louisiana. Similarly, the minimum SCB J_c values of 0.6 and 0.5 kJ/m² were established for Level 2 and Level 1 asphalt mixtures to avoid crack related problems, respectively. Both, the HWTT and SCB test criteria considered the influence of traffic as demonstrated with the different test criteria for Level 2 (high traffic) and Level 1 (low traffic) asphalt mixtures.

A draft sampling and testing plan of the specifications was also proposed while acknowledging the need to collect more field and laboratory performance data to validate the initial performance test criteria.

Conducting Benchmarking studies. LaDOTD validation of the initial performance test criteria was based on historical database of HWTT and SCB results from LTRC for an array of plant-produced asphalt mixture types as well as cores from various locations across the State. The database was supplemented with additional performance tests from 11 plant-produced asphalt mixtures and cores from 6 field projects designed and produced in accordance with the BMD specifications (study conducted between 2011–2014).⁽³⁴⁾ In total, HWTT and SCB results were available for 51 asphalt mixtures. Based on the results of the analysis, the following findings and conclusions were made:⁽³⁴⁾

Benchmark studies were used as an initial check of the test criteria.

- HWTT:
 - 90 percent of evaluated asphalt mixtures passed the proposed initial criteria specified for acceptable rutting resistance. The criteria for unmodified and polymer-modified binders appeared to be appropriate for LaDOTD asphalt mixtures.
 - Improved or similar performance was observed for the 11 asphalt mixtures produced using the LaDOTD BMD specifications in comparison to the asphalt mixtures produced using the 2006 LaDOTD specifications.
 - Improved rutting performance was observed for the polymer-modified mixtures in comparison to the unmodified asphalt mixtures.
- SCB:
 - 38, 68, 91, and 20 percent of evaluated asphalt mixtures containing PG 64-22, PG 70-22M, PG 76-22M and PG 82-22CRM passed the initial proposed criteria for acceptable cracking resistance, respectively. These percentages were irrespective of whether asphalt mixtures were designed to meet HWTT and SCB parameters.
 - 64 percent of the asphalt mixtures designed according to the LaDOTD BMD specifications met or exceeded the initial cracking criteria.
 - Asphalt mixtures containing PG 76-22M modified binder outperformed the asphalt mixtures containing other asphalt binders.
 - The comparison of the plant-produced specimens to the core specimens revealed a potential effect for specimen type on the SCB J_c . Thus, requiring further

investigation before implementation of the use of field cores for acceptance practices.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. LaDOTD funded several research studies to evaluate the sensitivity of performance tests to material properties using typical asphalt mixtures from Louisiana. The studies evaluated the effect of several factors such as the binder type and grade (e.g., unmodified versus polymer-modified), recycling type and content (e.g., RAP versus RAS), testing devices (e.g., load frames from different manufacturers), specimen type (e.g., gyratory compacted specimens versus field cores), in-place asphalt density achieved by different construction practices, etc.

Based on a contractor experience with field projects, the following observations were made:

- The specification changes made by LaDOTD to the volumetric design of asphalt mixtures (e.g., decrease in N_{design} , increase in VMA by 0.5 percent) were the right step towards a successful implementation of HWTT and SCB performance tests. These volumetric design changes helped and guided contractors in their effort to meet the applicable performance test criteria.
- Changes to asphalt mixtures to get acceptable performance testing values were generally material specific. In particular, the performance test results were found to be sensitive to the aggregate type and properties (e.g., specific gravities, absorptions, particle shapes). For example, asphalt mixtures using limestone aggregates did not generally exhibit difficulties in meeting performance tests criteria. In some other cases, reducing the amount of natural sand and the passing No. 200 sieve were necessary to meet performance tests criteria.
- An increase in binder content by 0.2–0.3 percent was generally observed. Nonetheless, this increase was mainly driven by the decrease in N_{design} and the increase of VMA requirements. An increase in binder content to meet the SCB J_c was not always necessary. There was specifically a need to increase the effective binder content of the mixture by restructuring the aggregate gradation and bin percentages. Meeting the HWTT requirement was generally not an issue.
- Because of the observed sensitivity of performance tests to asphalt mixture properties and composition, calibrations of the asphalt plant's cold feed bins, RAP feed bins, weigh bridges, etc. have become more critical for the production of an asphalt mixture that is in compliance with specifications.

Calibration of the plant's weigh bridges became more important.

Task 6: Specifications and Program Development.

Conducting Pilot Projects. In 2013, LaDOTD conducted pilot projects in 6 of the 9 districts. The aims of the pilot projects were two-folds: 1) to work out asphalt mix design requirements, sampling, and testing logistics; and 2) to validate the established threshold criteria for HWTT and SCB test parameters. The pilot projects also facilitated the early buy-in from the industry before full implementation into the standard specifications in 2016.

A pilot project was constructed in 6 of the 9 districts. Full implementation followed 3 years later.

Based on a contractor experience with field projects, the following observations were made:

- The initial challenges with implementing the HWTT and SCB tests were mainly related to equipment usage and analysis of test results. Contractors needed to gain confidence in the performance tests' equipment and results.
- The turnaround time on the SCB test results is long due to the 5 days oven-aging of SCB specimens prior to testing. A simplified aging protocol or a J_c -based relationship between short- and long-term aged properties of plant-produced asphalt mixtures is needed for the implementation of SCB test as part of acceptance during production.
- The BMD resulted in more consistent asphalt mixtures and allowed for the use of more RAP in asphalt mixtures.
- The validation and approval process of plant-produced asphalt mixtures is a critical and important step of the process in order to make sure asphalt mixtures are in compliance with specifications.
- Including and meeting PWL specifications during production resulted in plant-produced asphalt mixtures generally meeting the requirements for performance tests criteria.
- The help and support of LaDOTD with performance tests (training on equipment and test result calculations) were essential, especially at the beginning, in order to make sure that tests are being properly conducted in the contractor laboratory. Less support from LTRC was needed once the contractor gained the necessary experience with performance testing.
- No issues or challenges in meeting in-place density or ride quality requirements were observed or encountered. In general, density was easier to achieve with a lower number of passes mainly due to the observed increase in binder content of mixtures.

Final Analysis and Specification Revisions.

A phased-in approach for implementation of BMD was used. The results and findings from the research studies, benchmarking studies, and pilot projects were initially implemented in the *PART V—ASPHALT PAVEMENTS* of the *2016 Standard Specifications for Roads and Bridges*, which was later amended in 2018.⁽²⁹⁾

LaDOTD recognizes that the implementation of SCB test for acceptance is tied to the ability of testing aged specimens that are representative of a future critical pavement condition for cracking while keeping in mind the need for a quick turnaround time for test results.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. LaDOTD requires technicians to be certified and/or qualified for performing design, sampling, testing, and inspections. Technicians for both the contractor and LaDOTD need to be qualified and/or certified for testing according to the following levels for Asphalt Plant Technician: Qualified Aggregate Tester; Qualified Asphalt Concrete Plant Level I; Certified Asphalt Concrete Plant Level II; and Certified Asphalt Concrete Plant Level III. LaDOTD updated the Asphalt Concrete Plant Level II and Level III certifications to include both the HWTT and SCB performance testing.

Establishing or Updating Laboratory Accreditation Program Requirements. LaDOTD requires laboratories to be accredited by an accreditation agency approved by LaDOTD. This includes LaDOTD central materials laboratory and districts' laboratories. Furthermore, technicians that are involved in testing of asphalt mixtures for acceptance are required by LaDOTD to participate in a statewide proficiency testing program. Under this program, technicians need to fabricate and test specimens for Gmm, volumetric properties, and HWTT. The reported test results are analyzed to ensure that technicians are properly performing the tests in accordance with applicable standards.

Central and district laboratories must be accredited. Technicians doing acceptance testing are required to participate in an annual proficiency program.

Task 8: Initial Implementation.

The initial implementation of BMD by LaDOTD was in 2016. In 2018, LaDOTD implemented additional changes/improvements to PART V—ASPHALT PAVEMENTS of the 2016 standard specifications.

Prior to the 2018 standard specifications, contractors were required to get the JMF approved for each district separately. After the latest specification revisions, the JMF is only approved once at the State level. It should also be noted that for the past three years LaDOTD placed on average about 1.5 million tons of asphalt mixture per year. Accordingly, LaDOTD in general receives a limited number of JMF for acceptance and approval.

Once a plant is producing an acceptable JMF, the JMF production need to be kept within the specified tolerances. For plant QC, a subplot for *Section 502 Asphalt Concrete Mixtures* is defined as 1,000 tons and a lot is defined as 5,000 tons of produced asphalt mixture from one JMF that is consecutively sent to a single project.

During production, the LaDOTD's certified asphalt plant inspector randomly visits and inspects asphalt plants, sample and test material, and review documentation to ensure conformance to specification requirements. The asphalt mixture is tested for rutting and moisture susceptibility using HWTT every 20,000 tons of production per JMF (this is increased to every 10,000 tons for Section 501 asphalt mixtures). The HWTT results are used as a go/no-go or pass/fail criteria during production. The SCB test is currently not implemented during production due to the extended turnaround time for test results that is associated with the 5 days oven aging of compacted SCB specimens before testing. Thus, LTRC is in the process of developing an approach to estimate SCB test results for long-term aged specimens based on testing conducted on short-term aged specimens.

OBSERVED BENEFITS

The use of BMD on field projects allowed contractors to utilize innovative and recycled materials (e.g., RAP, warm mix additives) in order to produce asphalt mixtures that are in compliance with LaDOTD specifications. Performance testing helped in designing asphalt mixtures with higher RAP contents; thus, allowing for the production of economical and environmentally friendly asphalt mixtures without jeopardizing performance.

Using collected field pavement performance, LTRC is working on quantifying and documenting the cost-benefit of the BMD specifications in comparison with standard asphalt mix design specifications. The asphalt mixtures designed using the BMD approach were in general easier to compact in the field and to reach target in-place density. This observed improvement in the in-place pavement density is expected to lead to increase in asphalt pavement service life.

LaDOTD believes that the implementation of BMD is likely to result in cost savings by providing contractors with more flexibility during the asphalt mix design and allowing more opportunities to use recycled materials without jeopardizing asphalt pavement performance.

FUTURE DIRECTION

LaDOTD has been successfully using the BMD approach for almost all of its asphalt mixtures. The BMD is primarily founded on the HWTT and SCB, with which LaDOTD has had a long history of using them. LaDOTD desires to use the SCB performance test as 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.

The implementation of the BMD for acceptance necessitates improvements to the current long-term oven aging procedure for SCB test specimens, or the use of other surrogate tests that are simple and quick to run. A series of studies and activities are needed in order to ensure full implementation of BMD for design and acceptance. Some examples are provided below:

- Continue monitoring the field pavement performance and use information to validate and modify as needed the BMD approach and the established performance test criteria.
- Develop a procedure for considering the effect of long-term oven aging on the SCB J_c results of short-term aged specimens.
- Establish and/or implement necessary precision and bias statements for HWTT and SCB performance tests.
- Document the cost-benefit of the BMD specifications in comparison with standard asphalt mix design specifications.

The full implementation effort needs to be supplemented with proper communication, training and education activities. Contractors will need to stay involved and informed about any specification changes and their related impact on their produced asphalt mixtures.

CHAPTER 5 VIRTUAL SITE VISIT: MAINEDOT (APRIL 2020)

INTRODUCTION

MaineDOT's goal is to tie asphalt mix design to pavement structural design and pavement performance. The long-term plan is to evolve 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.

The "why" was to address an immediate need of durability and raveling issues that went beyond

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 State DOTs that 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 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.^(35,36)

A few years later, MaineDOT was introduced to the direct tension cyclic fatigue (AASHTO TP 107, AASHTO TP 133) and stress sweep rutting (SSR) (AASHTO TP 134) tests that they considered to be used for higher profile paving projects.⁽³⁷⁻³⁹⁾ 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 HWTT to evaluate their asphalt mixtures to immediately address durability and raveling issues.^(40,41) 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 asphalt mixtures along with the use of HWTT as part of an asphalt mix design and verification process for certain projects (based on roadway classification).

MaineDOT recognizes the need to move beyond volumetric properties for asphalt mix 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 (IDT) cracking test (formerly known as IDEAL-CT) (ASTM D8225) and the ideal shear rutting test (IDEAL-RT), respectively.^(16,42) Both of these tests are similar to Marshall stability

test and can be easier and simpler to implement as part of a routine asphalt mix design and to use in their QA program (process control and QC, agency acceptance, independent assurance, etc.).

The direct tension cyclic fatigue and SSR using the AMPT involves the prediction of pavement performance over time. This helps MaineDOT in making early and informed decisions on the type and quality of their asphalt mixtures while avoiding 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 binders. The AMPT performance tests are also used as a reference for comparison and better selection of 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., 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 performance tests with acceptable relation to field pavement performance to ensure: 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 a binder supplier to acquire IDT 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–Volumetric Design with Performance Verification* through *Approach C– Performance-Modified Volumetric Design* 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 mix design to BMD. 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 mix design process using the HWTT. Figure 12 shows a flowchart of the overall asphalt mix design.

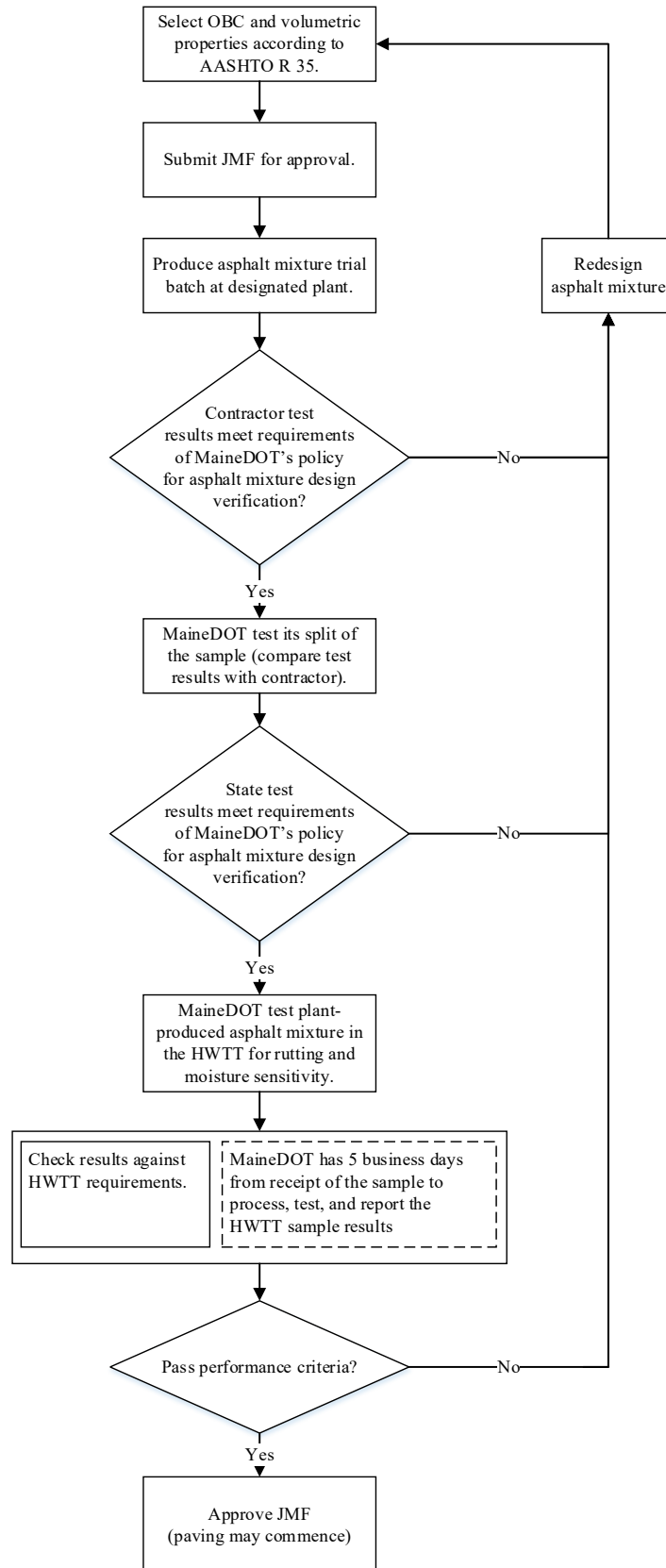


Figure 12. Chart. Overview of MaineDOT's asphalt mix design approach using HWTT.

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 23.⁽⁴³⁾ Table 24 summarizes the HWTT conditioning of laboratory and plant-produced asphalt mixtures established by MaineDOT for asphalt mixtures. The design, verification, QC, and quality acceptance tests for this mixture are performed at 65 gyrations. The contractor then submits a JMF for MaineDOT’s approval.

Table 23. MaineDOT Specifications for Mix Design Volumetric Properties.

Design ESAL’s (millions)	Required Density (% of Gmm)			VMA (Minimum %)					VFA (Minimum %)	Dust-to-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 and 4.75 mm NMAS asphalt mixtures, the maximum VFA is 82 and 84 percent, respectively.

Table 24. Summary of Short and Long-Term Conditioning of Laboratory and Plant-Produced Asphalt Mixtures by MaineDOT.

HWTT Conditioning	Laboratory-Produced Asphalt Mixture	Plant-Produced Asphalt Mixture
Short-Term Oven Aging	Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C). ⁽⁴⁴⁾	Reheated at compaction temperature.
Long-Term Oven Aging	0 hours	0 hours

The JMF is approved in accordance with the MaineDOT policies and procedures for asphalt mixture sampling and testing manual.⁽⁴⁵⁾ The contractor submits a new JMF for approval each time a change in material source or material properties is proposed. Asphalt 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 to check that the results meet the requirements of MaineDOT’s policy for mix design verification.⁽⁴⁵⁾ MaineDOT will then test its split of the sample and the results of the two split samples are compared. If the asphalt mixture meets MaineDOT’s requirements for mix design verification, the JMF is approved.

For those projects requiring asphalt mixtures to meet rutting and stripping tests, the plant-produced asphalt mixture will then be tested for rutting and moisture sensitivity using the HWTT according to AASHTO T 324 and the MaineDOT’s policy for modifications to AASHTO T 324 (dated March 1, 2019).^(9,46) The sample will be required to meet the applicable requirements of table 25 for JMF approval.

The MaineDOT’s HWTT specifications for asphalt mix design verification and acceptance (table 25) is a function of the traffic level and priority; inferred from the three different binder PGs. The testing temperature is also adjusted based on the required minimum PG of the binder.

In comparison to AASHTO M 323, “Standard Specification for Superpave Volumetric Mix Design” and AASHTO R 35, “Standard Practice for Superpave Volumetric Design for Asphalt Mixtures,” the following key modifications are implemented by MaineDOT to their volumetric design criteria (table 23 to table 26):

- Increased the VMA requirement by 1 percent for asphalt mixtures with an NMA between 9.5 and 25 mm.
- Increased, in particular, the upper limit requirement for VFA.
- Decreased N_{design} for design and acceptance of asphalt mixtures to 65 gyrations.

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by allowing more binder into the mixture without jeopardizing its resistance to rutting (the lower the N_{design} and the higher the specified VMA, the higher the binder content for a given air void level).

Table 25. MaineDOT Specifications for Plant-Produced Mix Design Performance Testing.

Specified PG	Test Temperature (°C)	Maximum Rut Depth (mm)	Minimum Number of Wheel Passes	Minimum Allowable Number of Wheel Passes to 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

Table 26. Summary of MaineDOT Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Asphalt Mixture Type (NMA)				
	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm
N_{design}	↓	↓	↓	↓	↓
Density at N_{design}	↔	↔	↔	↔	↔
Density at N_{max}	↔	↔	↔	↔	↔
Design Binder Content	–	–	–	–	–
VMA	↑	↑	↑	↑	↔
VFA	↑ UL	↑ UL	↑ UL	↑ UL	↑ UL
Dust-to-binder ratio	↔	↔	↔	↔	↔
HWTT Wheel Passes at 12.5 mm Rut Depth	Min	Min	Min	Min	Min
HWTT Wheel Passes to SIP	Min	Min	Min	Min	Min

–indicates not applicable or not specified; Min=minimum; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit.

IMPLEMENTATION PROCESS OF BMD

The following section summarizes MaineDOT’s experience with BMD implementation in terms of the eight tasks identified in figure 2. As noted before, the tasks organize the various activities

involved in the implementation of a BMD program that a State DOT can consider as part of its own effort to putting BMD into practice.

Task 1: Motivations and Benefits of BMD.

The motivation for implementation of HWTT in MaineDOT was the immediate need to address durability and raveling issues. MaineDOT QA specifications (i.e., PWL) aimed at ensuring the consistency of the asphalt mixture during production and did not necessarily target a desired performance level.

Assuring long-term performance of asphalt pavements is challenging with volumetric-based asphalt mix design. Thus, MaineDOT recognized the potential benefits with the implementation of performance tests to balance the stability/rutting and cracking/durability performance of asphalt mixtures.

Task 2: Overall Planning.

Identification of Champions. State DOT champions were committed to implementing the BMD program and provided leadership for the various implementation activities. Thus, MaineDOT has been leading and investing significantly in the process to develop and implement BMD for all of its asphalt mixtures. Contractors were also generally supportive of the BMD approach.

MaineDOT communicated with stakeholders the need and the anticipated enhancements in the quality of asphalt mixtures by having the HWTT for design and acceptance. For instance, this helped MaineDOT in securing the necessary management support and commitment from the State DOT throughout the implementation process of HWTT to fund pertinent activities (e.g., research, equipment purchasing) and allocate needed resources (e.g., dedicated skilled and trained technicians, laboratory space).

The champion gained management support for equipment purchases, additional staffing, and laboratory space.

Establishing a Stakeholders Partnership. While an official joint task force with industry and academia was not established, MaineDOT kept the industry involved during the process through continuous communications and discussions about forthcoming specification changes, and the opportunity to provide comments and inputs on any suggested changes.

Doing Your Homework (Identifying the Issues, Identifying Resources, and Reviewing Literature). MaineDOT immediate issues with their asphalt mixtures was durability and raveling. To improve the resistance of the asphalt mixtures to cracking, a cracking performance test is being considered to supplement the benefits observed with the HWTT.

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 IDT cracking test can be completed. Essentially, the

Differences between performance testing related to specimen fabrication and testing times impacted the decision for the type of performance test.

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.

The current staffing level is considered proficient and adequate for the current plan because the IDT cracking test is simple and quick to complete.

MaineDOT conducted a literature review of existing research studies and specifications from other State DOTs pertinent to performance tests and their criteria.

Establishing Goals. MaineDOT's goal has been the application of the BMD program onto all interstate and high investment State paving projects for asphalt mix design and acceptance.

The goal for application of BMD was for all interstate and high investment projects.

Identifying Available External Technical Information and Support. 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 by MaineDOT to provide proper technical inputs and feedback on the process for establishing and validating performance test criteria for specifications is valuable.

MaineDOT also expressed the need as a State DOT 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.

Developing an Implementation Timeline. While an implementation timeline has not been developed yet, MaineDOT noted that such timeline is critical for a State DOT to succeed. It will help guiding the efforts and activities to be accomplished by a State DOT. Efforts should be made by a State DOT to avoid as practical as possible delays and deviations from the set initial timeline.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. Raveling, rutting and cracking were the primary asphalt pavement modes of distress identified by MaineDOT to be considered in the BMD process.

Identifying and Assessing Performance Test Appropriateness. The top three factors for MaineDOT in selecting a performance test were: field validation, material sensitivity, and repeatability/reproducibility.⁽¹⁷⁾ 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, binders, recycled materials, additives), air voids, and aging is also as important. For MaineDOT, having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful

implementation of specifications. Other important factors are sample preparation, equipment cost, applicability to laboratory-molded specimens and field cores.

With these factors in mind, MaineDOT has been evaluating multiple asphalt mixture performance tests for possible use into future implementation of a BMD for design and acceptance. A final decision has not been made, but several tests are currently under evaluation.

MaineDOT was introduced to HWTT and direct tension cyclic fatigue tests during their involvement with the AASHTO SHRP2 Performance Specifications for Rapid Renewal (R07). MaineDOT then selected the HWTT device after reviewing related specifications and procedures for other State DOTs (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 IDT 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 State DOTs and research centers. Preliminary testing was first conducted by MaineDOT to verify the IDT cracking test before moving forward with a comprehensive experimental plan to test asphalt mixtures. Results can be obtained extremely quickly from the IDT cracking test. The similarity between the sample preparation of the IDT 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 IDT 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.

Validating the Performance Tests. The HWTT performance criteria were initially based upon specifications from other State DOTs (especially neighboring states), and revised based on comparison of test results to historical field pavement performance. In a continuous effort to advance implementation,

A forensic study of pavements of known field performance was a key in validating the HWTT results.

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.⁽⁴⁷⁾ 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 mix 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.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. MaineDOT invested in new equipment and accessories in order to undertake performance testing including one AMPT, two HWTT devices, and two IDT cracking devices.

Performance testing is primarily done at the central lab.

Sample fabrication was found to be the bottleneck for MaineDOT when it comes to performance testing and had the biggest impact on resources. Thus, an additional Superpave gyratory compactor was procured in order to increase productivity of fabrication processes for performance testing.

Managing Resources. In general, funding for acquiring new equipment in laboratories have not been a major issue for MaineDOT. This is mainly due to a strong internal support of the MaineDOT administration throughout the various implementation efforts and activities. However, there was a need for additional resources to create new areas in the laboratories to accommodate 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 IDT 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.

Additional staff were hired, and additional space was needed.

Trained and dedicated technicians on the procedures and analysis of test results are 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.

Conducting Initial Training. MaineDOT partnered with contractors and provided them with “informational testing” from the HWTT 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 mix 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 IDT 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.

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 asphalt mixture. The similarities in size and shape of the specimens for the HWTT and IDT cracking test simplified the process and made it convenient. All that was needed was few extra boxes of plant-produced asphalt mixtures.

Efficiencies were found in predicting the sample weight to obtain the target air voids and identifying technician responsibilities.

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.

Evaluating Performance Testing. 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 HWTT device manufacturers had different analysis methodologies that led to differences in some of the calculated test parameters (MaineDOT has HWTT 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.⁽⁴⁶⁾ MaineDOT may face a similar challenge with the IDT cracking test (ASTM D8225).

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:

Robust procedures were needed for the calculation, analysis, and reporting of results.

- 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.

Conducting Inter-Laboratory Studies. The AASHTO T 324 performance tests have no information regarding the precision and bias of the test method. This may create a potential issue if two separate laboratories achieve different test results for the same asphalt mixture.

Multiple round robins led to improved specimen fabrication and testing procedures.

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, HWTT 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.

MaineDOT has plans to participate in AMPT ruggedness testing for direct tension cyclic fatigue and SSR.

Task 5: Establishing Baseline Data.

Reviewing Historical Data & Information Management System. Historical data on field performance of asphalt mixtures in Maine was reviewed and used in the selection of the performance tests criteria. In other words, the test results of local asphalt mixtures need to agree with known and observed field pavement performance.

Conducting Benchmarking studies. MaineDOT based its selection of performance tests criteria on existing research studies and specifications from other State DOTs. 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.

Benchmarking and other States' specifications allowed for setting initial criteria.

MaineDOT continues to build-up its database of performance test results on asphalt mixtures and makes use of it for establishing a State-specific relationship between test results and field performance in Maine.

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., IDT cracking test) as part of a study initiated in 2019 to help address and identify potential added benefits for antistripping treatments and polymer-modified 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.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. 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 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 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.

Task 6: Specifications and Program Development.

Developing Pilot Specifications and Policies.

Throughout the process, MaineDOT developed and revised as needed the HWTT related specifications and policies. This included the following:^(43,45,46)

- Section 401 – Hot Mix Asphalt Pavement (HMA Hamburg Wheel Tracker Specification). Special Provision, Division 400, Pavements.
- MaineDOT Policies and Procedures for HMA Sampling and Testing.
- MaineDOT Policy, HMA Hamburg Wheel Tracker Testing.

Specifications and policies for the HWTT were created and reviewed prior to using them on pilot projects.

Conducting Pilot Projects. 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.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. 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.

Establishing or Updating Laboratory Accreditation Program Requirements. Currently MaineDOT 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.

Task 8: Initial Implementation.

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.

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 binders in approximately 50% of the projects in the State, expanded requirements for use of liquid anti-strip additives, and a consolidated asphalt mix design performed at 65 gyrations.

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. Thus, the HWTT test is included as part of production testing.

Initial implementation resulted in fewer premature pavement failures. About half of the mixtures submitted needed modification to pass the HWTT.

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 HWTT 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 HWTT requirements (table 25). If a sample fails to meet the criteria in table 25, 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. Asphalt 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 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 NMAAS.

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 binders was observed. No substantial difference in binder content or RAP content was observed.

By implementing proper performance tests for rutting and durability/cracking 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.

OBSERVED BENEFITS

A number of pavements throughout the State experienced significant raveling in asphalt mixture overlays leading to an estimated loss in MaineDOT pavements' service life of 20% in one construction season.^(41,48) This was estimated to be equivalent to about \$15 million in one year. Overall, with the implementation of the HWTT in Maine, fewer cases of premature failures were

Fewer cases of premature failure were observed resulting in an estimated cost savings of \$7.5 million per year.

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 through restoring pavements' service life 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 mixture 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 State DOTs 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.

CHAPTER 6 VIRTUAL SITE VISIT: NJDOT (MAY 2020)

INTRODUCTION

To address the ongoing concerns with pavement durability and cracking, specialty asphalt mixtures designed with performance testing were developed in coordination with the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers University.⁽⁴⁹⁾ The performance tests included the Asphalt Pavement Analyzer (APA), the Overlay Tester (OT), and the Flexural Bending Fatigue (FBF).^(7,50,51) This overall effort was in line with NJDOT's goal to increase pavements' longevity by tying asphalt mix design to pavement structural design and pavement performance. The following five specialty asphalt mixtures were developed, each with their own specific purposes:⁽⁵²⁾

Performance tests were used to design asphalt mixtures to specifically address durability and cracking to increase pavements' longevity.

- **BDWSC.** The Bridge Deck Waterproofing Surface Course (BDWSC) is utilized as a waterproof surface course for bridge deck overlays. The BDWSC was developed in 2007 and was utilized on several bridge decks requiring an AC overlay. The decline in BDWSC use over the years has been driven primarily by other factors not necessarily related to its good performance (e.g., BDWSC masks deteriorated and delaminated areas in a concrete bridge deck). The BDWSC performance testing includes requirements for the APA rut depth and the FBF cycles to failure.
- **HPTO.** The High-Performance Thin Overlay (HPTO) is utilized as a thin-lift surface course for primarily pavement preservation purposes. HPTO has also been utilized as a leveling course in some areas. The HPTO was developed around 2008 and since ~2014 it has been heavily used as a rehabilitation/pavement preservation surface course. Testing for HPTO originally included the APA. The OT was added at a later time based on feedback from observed field performance.
- **BRIC.** The Binder Rich Intermediate Course (BRIC) is utilized as a reflective cracking relief interlayer material to help retard reflection cracking on composite pavements. The BRIC was developed in 2009. It is overlaid primarily with SMA (HPTO was used occasionally). The SMA overlay was found to outperform the conventional asphalt overlays. The BRIC includes a requirement for the APA rut depth, and in the case of cracking includes a requirement for the OT number of cycles until failure.
- **BRBC.** The Binder Rich Base Course (BRBC) is utilized as the base layer in the design and construction of perpetual pavements. It was developed in 2010 for a rubblization/perpetual pavement project on Route I-295. Since this project, BRBC has been proposed for use on other rubblization/perpetual pavement projects in New Jersey. The BRBC includes a requirement for the APA rut depth, and in the case of cracking includes a requirement for the FBF cycles until failure.
- **HRAP.** The Hot Mix Asphalt High RAP (HRAP) is utilized when a high percentage of RAP is used in the asphalt mixture (at least 20 percent RAP for surface course and 30 percent RAP for base or intermediate course). It was developed in 2012 and has been used since 2013. Performance tests criteria are based on database of typical virgin (i.e., 0 percent RAP) asphalt mixtures. The specification includes requirements for both the APA rut depth and OT number of cycles until failure.

NJDOT uses as much as 2 million tons of asphalt mixtures per year throughout the State. Between 2015 and 2019, all specialty asphalt mixtures comprised on average about 10 percent of the total asphalt tonnage placed in the State (figure 13). The use of specialty asphalt mixtures steadily increased from 5.1 percent in 2015 to as much as 16.8 percent in 2018. In 2019, specialty asphalt mixtures comprised 8.3 percent of the total asphalt tonnage placed. The observed drop in the percent use of specialty asphalt mixtures last year is mainly attributable to project prioritization and selection process (resurfacing projects not continuously ranking high in the process) in conjunction with delays in the procurement process (complexity of requirements stipulated in the procurement rules pushed back some of the projects until next year). Among all five specialty asphalt mixtures, HPTO has been used the most.

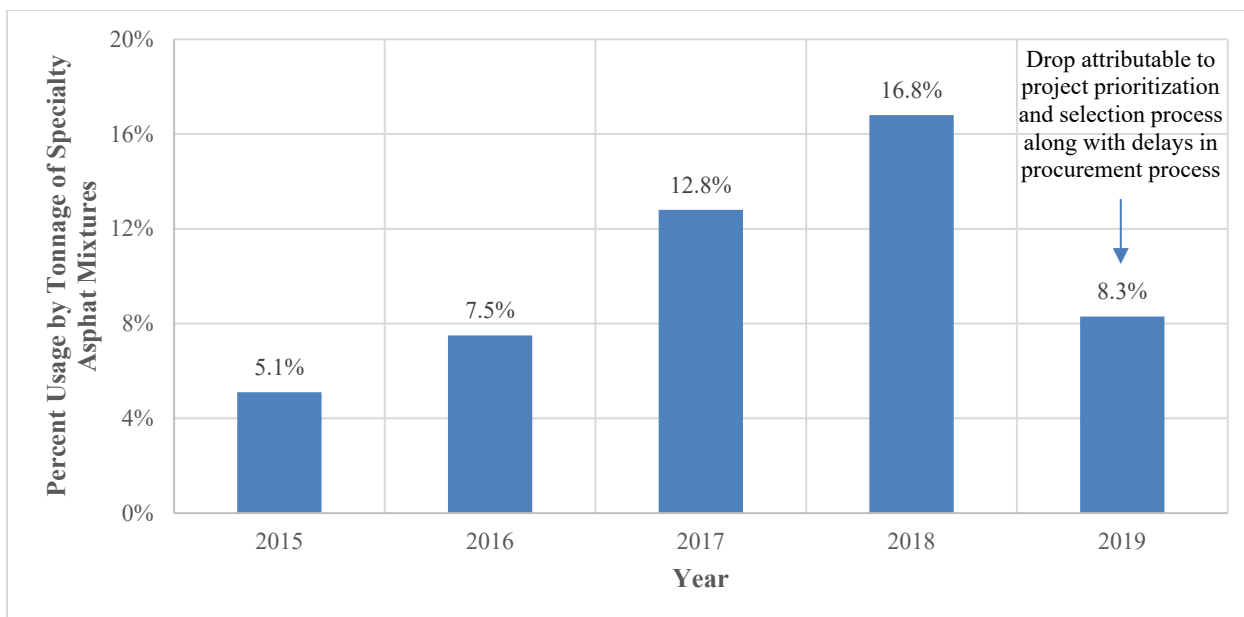


Figure 13. Chart. NJDOT annual usage for specialty asphalt mixtures.

In summary, the deteriorating transportation infrastructure, the continuous need to increase performance life of asphalt pavements to stretch the budget, and the increase in traffic volumes, led NJDOT to implement specialty asphalt mixtures with performance testing. These mixtures are selected based on the extreme needs of the pavement structure in question (composite pavement, bridge deck overlay, etc.). Each specialty mixture is required to undergo performance testing during the mix design, test strip, and project construction phase to ensure the final asphalt mixture achieves the desired performance to the specific pavement structure.

BMD APPROACH

NJDOT developed and implemented five specialty asphalt mixtures: BDWSC, HPTO, BRIC, BRBC, HRAP. Figure 14 shows a flowchart of the overall BMD for all five specialty asphalt mixtures. The flowchart highlights the major steps for undertaking an asphalt mix design according to NJDOT specifications and identifies the activities that fall under the responsibility of the contractor or agency. The requirements for volumetric design, gyratory compaction efforts, and performance testing are summarized in table 27 through table 29.

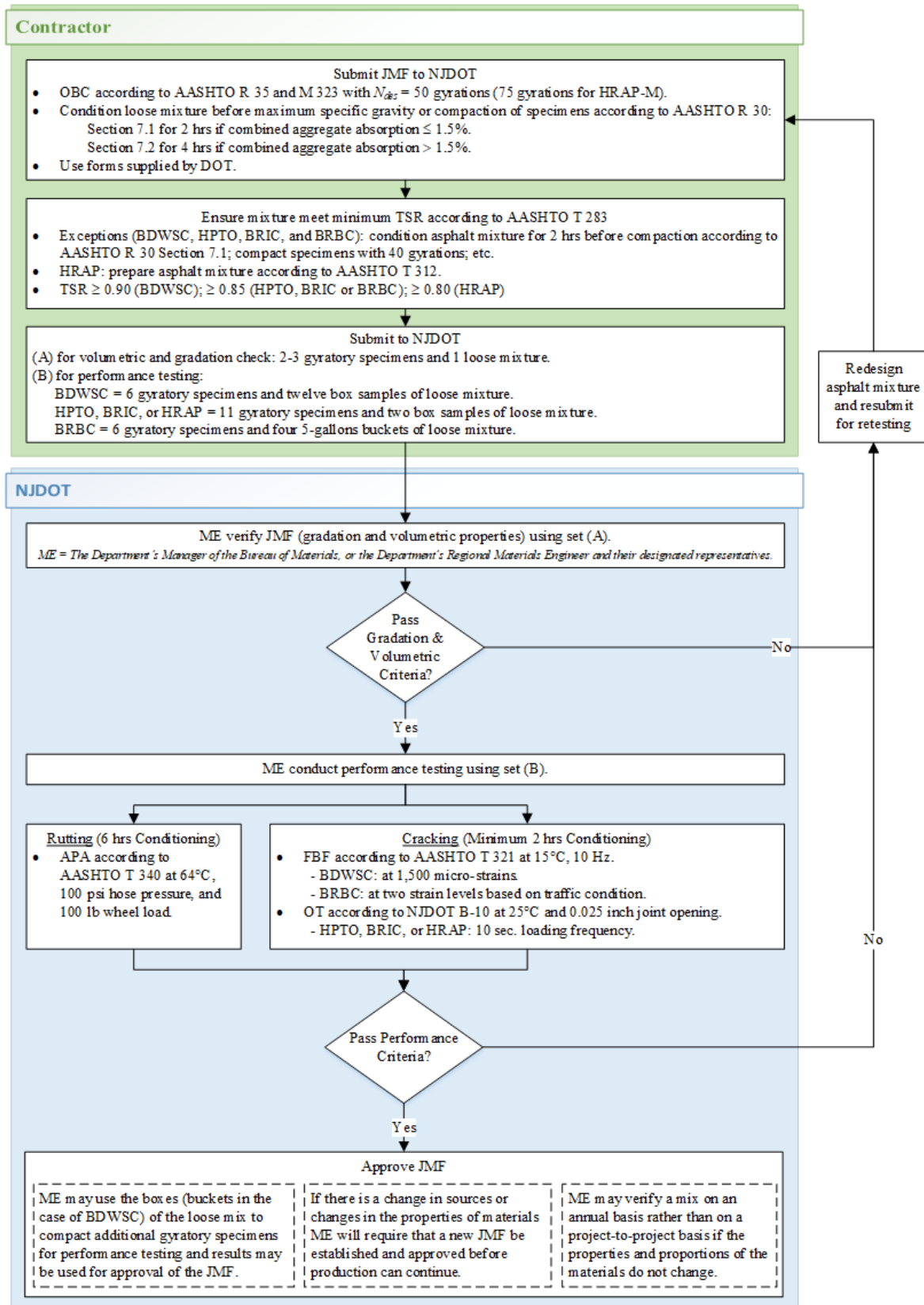


Figure 14. Chart. Overview of NJDOT BMD approach for specialty mixes.

Table 27. NJDOT Specifications for Volumetric Design Requirements.

Mixture Type	Binder Content (%) [*]	Required Density (% of Theoretical Max. Specific Gravity)		VMA (Minimum %)					VFA (%)	Dust-to-Binder Ratio	Drain-down [#] (%)
				N _{design}	N _{max}	NMAS (mm)					
		25	19			12.5	9.5	4.75			
BDWSC	≥7.0	99.0	–	–	–	18.0	18.0	–	90–100	0.3–0.9	≤0.1%
HPTO	≥7.0	96.5	≤99.0	–	–	–	18.0	–	–	0.6–1.2	≤0.1%
BRIC	≥7.4	97.5	≤99.0	–	–	–	–	18.0	–	0.6–1.2	≤0.1%
BRBC	≥5.0	96.5	–	–	13.5	–	–	–	70–80	0.6–1.2	≤0.1%
HRAP											
L	–	96.0	≤98.0	13.0	14.0	15.0	16.0	17.0	70–85	0.6–1.2	–
M	–	96.0	≤98.0	13.0	14.0	15.0	16.0	17.0	65–85	0.6–1.2	–

–Not applicable; ^{*}binder content by ignition furnace; [#]AAHTO T 305; minimum of 20% RAP for HRAP surface course and 30% RAP for HRAP base or intermediate course; L=low design compaction level; M=medium design compaction level.

Table 28. NJDOT Specifications for Mix Design Gyrotory Compaction Effort.

Mixture Type	Compaction Level	ESALs (millions) [*]	N _{des}	N _{max}
BDWSC	–	–	50	–
HPTO	–	–	50	100
BRIC	–	–	50	100
BRBC	–	–	50	–
HRAP	Low (L)	<0.3	50	75
	Medium (M)	≥0.3	75	115

–Not applicable; ^{*}Design ESALs (Equivalent (80kN) Single-Axle Loads) refer to the anticipated traffic level expected on the design lane over a 20-year period.

Table 29. NJDOT Specifications for Mix Design Performance Testing Requirements.

Mixture Type	PG (AASHTO R 29)	Spec. Air Voids	TSR (AASHTO T 283)	APA @ 8,000 Loading Cycles, 64°C (AASHTO T 340) [*]	OT (NJDOT B-10)	FBF Life @ 15°C (AASHTO T 321)
BDWSC	– [#]	≤3%	≥90%	≤3 mm	–	>100,000 cycles @ 1,500 micro-strain
HPTO	– [#]	5.0±0.5%	≥85%	≤4 mm	≥600 cycles	–
BRIC	– [#]	3.5±0.5%	≥85%	≤6 mm	≥700 cycles	–
BRBC	– [#]	5.5±0.5%	≥85%	<5 mm	–	>100,000,000 cycles @ 100 micro-strain
HRAP						
Surface Course	64-22 [#]	6.5±0.5%	≥80%	≤7 mm	≥200 cycles	–
	64E-22 [#]	6.5±0.5%	≥80%	≤4 mm	≥275 cycles	–
Intermediate and Base Course	64-22 [#]	6.5±0.5%	≥80%	≤7 mm	≥100 cycles	–
	64E-22 [#]	6.5±0.5%	≥80%	≤4 mm	≥150 cycles	–

–Not applicable; ^{*}100 psi hose pressure and 100 lb per wheel load; [#]PG of asphalt binder is not specified and is determined by the mix design and mix performance testing however a certificate of analysis showing the PG continuous grading for the asphalt binder used in the mix design has to be submitted to ensure asphalt binder consistency throughout the production process.

In general, the NJDOT's BMD for designing asphalt mixtures and approving JMFs follows a combination of Approach A *Volumetric Design with Performance Verification* and Approach B *Volumetric Design with Performance Optimization*. During approval, the asphalt mixture has first to pass all gradation and volumetric property requirements before being evaluated in the designated performance tests. However, it should be noted that most of the volumetric properties for the specifications are modified from conventional asphalt mix design. Subsequently, the asphalt mixture needs to pass the performance criteria for both rutting and cracking. If the asphalt mixture fails any of the criteria, the contractor has to redesign the asphalt mixture and resubmit all necessary materials for JMF approval following the same process. This same methodology is conducted during three different phases; 1) mix design, 2) test strip, and 3) production.

An asphalt binder PG is not specified for any of the five specialty asphalt mixtures. The PG is determined by the asphalt mix design and performance testing. However, a certificate of analysis showing the PG continuous grading (AASHTO R 29) for the asphalt binder used in the asphalt mix design has to be submitted to ensure asphalt binder consistency throughout the production process.⁽⁵³⁾

The contractor submits with the asphalt mix design the TSR results (AASHTO T283). The asphalt mixture is conditioned for 2 hours according to AASHTO R 30 Section 7.1 before being compacted to 40 gyrations (BDWSC, HPTO, BRIC, and BRBC).⁽⁴⁴⁾ In the case of HRAP, the asphalt mixture is prepared according to AASHTO T 312 and tested according to AASHTO T 283. The asphalt mixture needs to meet the minimum TSR specified in table 29.

In comparison to AASHTO M 323 and AASHTO R 35, NJDOT implemented the following key modifications to their volumetric design criteria (table 27 to table 30):

- Specified 50 gyrations for design and acceptance of all five asphalt mixtures; with the exception of 75 gyrations specified for HRAP-M (design compaction level M—more than 0.3 million ESALS) (table 28).
- Specified a minimum binder content of 7 percent for BDWSC and HPTO, 7.4 percent for BRIC, and 5 percent for BRBC. In order to avoid bleeding of the asphalt mixture, a draindown requirement was also specified (AASHTO T 305).
- Increased the density requirement at the design number of gyrations (N_{des}) by 3 percent for BDWSC, 0.5 percent for HPTO and BRBC, and 1.5 percent for BRIC.
- Increased the density requirement at the maximum number of gyrations (N_{max}) by 1 percent for HPTO and BRIC; and omitted the requirement for BDWSC and BRBC.
- Increased the VMA requirement by: 3 and 4 percent for BDWSC with a nominal maximum aggregate size (NMAS) of 9.5 and 12.5 mm, respectively; 3 percent for HPTO; 2 percent for BRIC; 0.5 percent for BRBC; and 1 percent for HRAP.
- Increased the voids filled with asphalt (VFA) range by 20 percent for BDWSC; and the upper limit requirement by 5 to 7 percent for HRAP. No VFA requirements for HPTO and BRIC.
- Decreased the dust-to-binder ratio for BDWSC by 0.3 percent.

Table 30. Summary of NJDOT Modifications to AASHTO Standard Volumetric Design Criteria.

NJDOT Requirements	Mixture Type				
	BDSWC	HPTO	BRIC	BRBC	HRAP
N_{design}	↓	↓	↓	↓	↓
Density at N_{design}	↑	↑	↑	↑	↔
Density at $N_{max}^{\#}$	–	↑	–	↑	↔
Design Binder Content	Min	Min	Min	Min	–
VMA	↑	↑	↑	↑	↑
VFA	↑	–	↑	↔	↑UL
Dust-to-Binder Ratio	↓	–	–	–	–
Draindown (%)	Max	Max	Max	Max	–
PG	–	–	–	–	↔
APA	Max	Max	Max	Max	Max
OT	–	Min	–	Min	Min
FBF	Min	–	Min	–	–
TSR	Min	Min	Min	Min	Min

–indicates not applicable or not specified; Min=minimum; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑UL=increased upper limit.

The above changes to AASHTO M 323 and AASHTO R 35 aimed at increasing the durability and cracking resistance of an asphalt mixture by letting more asphalt binder into the mixture without jeopardizing its resistance to rutting (the higher the VMA, the higher the asphalt binder content for a given air void level).

Except for HRAP, the use of RAP is not allowed in any of the specialty asphalt mixtures. Furthermore, the fine aggregate for all four mixtures (i.e., BDSWC, HPTO, BRIC, and BRBC) has to be 100 percent stone sand (i.e., no natural sand).

For each asphalt mix design, the contractor submits to NJDOT two sets of samples: (A) 2–3 gyratory specimens and 1 loose mixture; and (B) 6–11 gyratory specimens and 2–12 box samples (5-gallon buckets in the case of BDSWC) of loose mixture. NJDOT first tests the set (A) samples and determine if the results meet the requirements of NJDOT for gradation and volumetric properties. If acceptable, NJDOT will then use set (B) samples for performance testing of the asphalt mixture (APA, OT, or FBF). The asphalt mixture will be required to meet all applicable requirements of table 27 and table 29 for JMF approval. Asphalt mix designs may be verified on an annual basis rather than on a project-to-project basis if the properties and proportions of the materials do not change. The contractor has to submit a new JMF for approval each time a change in material source or material properties is proposed.

IMPLEMENTATION PROCESS OF BMD

The following section summarizes NJDOT’s experience with BMD implementation in terms of the eight tasks identified in figure 2. As noted before, the tasks organize the various activities involved in the implementation of a BMD program that a State DOT can consider as part of its own effort to putting BMD into practice.

Task 1: Motivations and Benefits of BMD.

The early implementation of Superpave by NJDOT resulted in dense-graded asphalt mixtures that had coarser aggregate blend gradations, low binder contents, and were harder to place and compact. These asphalt mixtures were prone to poor longitudinal joint construction (generally lower in density) and to quicker failures due to durability and cracking related distresses. Furthermore, pavements under the jurisdiction of NJDOT are ~55 percent composite pavements; which made them prone to reflection cracking. Accordingly, NJDOT attempted to address the observed poor performance by decreasing the compaction effort to 100 gyrations from the initially selected design gyrations of 125; a gyration number that is used for a 20-year design traffic of more than 30 million equivalent (80 kN) single-axle loads (ESALs). To improve durability and cracking performance of dense-graded asphalt mixtures, the number of design gyrations were further reduced (around 2014) in an effort to increase the OBC; to 50 gyrations for design traffic less than 0.3 million ESALs (referred to as low design compaction level—L) and to 75 gyrations for design traffic greater than or equal to 0.3 million ESALs (referred to as medium design compaction level—M).

Adjusting gyrations and volumetric properties were not sufficient to address performance concerns of durability and cracking.

While, in general, reducing the number of design gyrations had shown improvements in the performance of asphalt mixtures throughout the State, it did not completely address all observed field performance issues. In several instances, NJDOT had to use proprietary asphalt mixtures for special applications. This prompted NJDOT to explore different ways for designing asphalt mixtures by supplementing volumetric-based methods with performance testing.

NJDOT and in collaboration with the CAIT at Rutgers University took steps to address the ongoing concerns with pavement durability and cracking. This consisted of reverse engineering satisfactory performance of particular specialty mixtures using performance tests specifically selected by the State. The purpose of this initiative was to increase competition (availability) and reduce cost by moving away from proprietary mixtures by reverse engineering.

Task 2: Overall Planning.

Identification of Champions. Internally, there was a champion that took the lead in the implementation effort. Continuous communication and partnership within NJDOT between materials, pavement design, and pavement management groups helped in validating and refining performance test criteria. Ultimately, the champion had to take the risk to try the new specialty mixtures on projects.

One of the roles of the champion was the coordination between all the different groups within the DOT.

Establishing a Stakeholders Partnership. Collaboration and cooperation between NJDOT, Rutgers University, and industry was important for a successful and smooth implementation of performance tests as part of asphalt mix design and acceptance. This involved good communication and continuous dialogue with the industry, knowledge transfer, and necessary education and training.

Externally, having trusted industry partners (i.e., asphalt binder suppliers, asphalt plants, contractors) supporting the implementation of specialty asphalt mixtures accelerated the learning curve. Communicating with contractors the impact of new specifications on the design and acceptance of their asphalt mixtures was key to facilitating implementation.

Rutgers University's CAIT Pavement Support Program (PSP) that is funded by the State Planning and Research (SP&R) Program and is responsible for providing pavement engineering support to the NJDOT's Pavement and Drainage Management Systems (P&DMS) Unit.

Doing Your Homework (Identifying the Issues, Identifying Resources, and Reviewing Literature).

Externally, having a strong and established relationship with academia (i.e., CAIT at Rutgers University) helped in developing performance testing for asphalt mixtures. Having an established program through the State such as the NJDOT PSP, which was funded by SP&R, to support critical and pressing research was key in the development and implementation. Pavement performance issues were identified and then research was conducted to identify solutions to make improvements.

Research with academia is a key to identifying solutions to improve pavement performance.

Establishing Goals. Initially, the performance testing was to be used for the mix design of specialty mixtures. That evolved to the use of performance testing in acceptance of the specialty mixtures. The future implementation continues to evolve, and plans have been made for BMD with the traditional dense-graded mixtures. This is a stepped approach. As milestones are reached for one step, work begins on the next step.

The initial goal for application of BMD was for specialty mixtures and it is now evolving to include dense-graded mixtures.

Identifying Available External Technical Information and Support. Externally, having a strong and established relationship with academia (i.e., Rutgers University) helped in developing performance testing for asphalt mixtures. Having an established program through the State such as the NJDOT PSP (funded by SP&R) to support critical and pressing research was key in the development and implementation.

Academia support from Rutgers University was a key to success.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. The early implementation of Superpave by NJDOT resulted in dense-graded asphalt mixtures that had coarser aggregate blend gradations, low binder contents, and were harder to place and compact.⁽⁵⁵⁾ These asphalt mixtures were prone to poor longitudinal joint construction (generally lower in density) and to quicker failures due to durability and cracking related distresses. Furthermore, pavements under the jurisdiction of NJDOT are ~65% composite pavements; which made them prone to reflection cracking.

Cracking from Superpave mixtures and composite pavements needed addressing.

Identifying and Assessing Performance Test Appropriateness. The APA is currently being used to evaluate the rut resistance of all five specialty mixtures. Originally, Rutgers University was

running Superpave Shear Tester (SST) on asphalt mixtures for rutting evaluation. However, the associated high cost for the equipment and time to prepare test specimens led researchers to abandon the SST and switch to the APA. The APA test results were relatively easy to analyze and interpret (pass/fail rut depth criterion at certain loading cycles). Rutgers University then developed a baseline database of the APA rut depth parameter for produced asphalt mixtures that was later correlated to field pavement performance.

When this BMD effort started, limited cracking tests were available. The most common test was the FBF test that got implemented for BDWSC and BRBC. During this effort, the OT was being introduced as a pass/fail type of test which seemed to address the needs of NJDOT for a representative cracking test that is simple and quick to run. Literature available then (2007–2009) indicated excellent correlation between the OT and field cracking for both composite and flexible pavements. It also indicated the sensitivity of OT to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials) and air voids; which was another important aspect (NJDOT had some concerns with mixtures with high RAP and low binder content). The OT also offered the ability to run the test on laboratory-prepared or field core specimens.

In the case of mix design, the top three factors for NJDOT in selecting a performance test were: field validation, repeatability, and specimen conditioning and testing time.⁽¹⁷⁾ Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of NJDOT’s motivations for implementation of performance tests. For NJDOT, having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications. Having qualified and trained technicians help to reduce the impact this factor might have on the overall implementation effort of performance tests. The duration needed for specimen conditioning and testing has been a key consideration in the development of test criteria and the implementation of any performance test into the specifications. Other important factors are sample preparation, material sensitivity, equipment cost, etc.

The top factors for selection of a performance test for asphalt mixture design were different than those for production.

Contractors also had to invest in certain equipment and associated training efforts. Having continuity and uniform performance testing methods across the State helps to reduce overall cost and accelerate implementation. NJDOT has to take into consideration the contractors’ learning curve and minimize frequent changes to test procedures and equipment.

Once these tests were implemented in design, there was a desire to use them for acceptance. The current phase of the implementation is looking at acceptance. NJDOT is particularly interested in effective and practical performance test methods for routine usage during production; so that test results can be tied to a pay factor for asphalt pavements. Thus, sample preparation, specimen conditioning and testing time, as well as equipment cost are currently the top three factors for NJDOT in selecting a performance test for asphalt mixture acceptance. Accordingly, the high-temperature IDT strength and the intermediate-temperature IDT Cracking (formerly known as IDEAL-CT) tests are currently being evaluated to assure that plant-produced asphalt mixtures meet the minimum performance requirements during production.^(16,56,57)

The high-temperature IDT strength and the intermediate-temperature IDT cracking test (ASTM D8225) are being researched by Rutgers University as surrogate performance tests during production. In general, the IDT tests are quick procedures that use currently available equipment in the laboratory with slight modifications as needed; thus, requiring minimal investments from both NJDOT and the industry. These tests entail a fewer number of specimens that are much simpler to fabricate and prepare (no cutting or gluing involved) and faster to test; thus, allowing for more tests to be completed within normal working hours. The implementation of such tests reduces the overall need for manpower and accelerates the time to test and report back the results of sampled asphalt mixtures during production to the contractor (quick turnaround time). NJDOT is planning on conducting IDT testing during production on upcoming pilot projects this construction season in order to establish a database of test results and validate the IDT tests criteria developed by Rutgers University. The success of this effort will facilitate the potential development and implementation of performance tests for dense-graded asphalt mixtures used in the State.

Validating the Performance Tests. Three methods of validating the performance tests have been used: 1) Special Pavement Study (SPS) -5 sections, 2) PMS data, and 3) ongoing monitoring of projects.

Performance tests were validated with multiple approaches: LTPP SPS-5 section, PMS data, and ongoing monitoring of projects.

Conflicting information, in particular, pertaining to the fatigue cracking performance of recycled asphalt mixtures were illustrated in the literature (while several studies described good correlations between OT results and field pavement performance of recycled asphalt mixtures others were reporting totally opposite results). This steered Rutgers University to further assess the ability of the OT results to predict field pavement performance. Accordingly, materials were evaluated from test sections at the New Jersey's Long-Term Pavement Performance (LTPP) SPS-5: Rehabilitation of Asphalt Concrete Pavements. The SPS-5 included sections with different AC overlay thickness (2 and 5 inches), milling surface (with and without milling), and RAP content (0 and 30 percent).⁽⁵⁴⁾ Cores taken prior to rehabilitation as well as retained loose asphalt mixtures from 1994 construction were evaluated in the OT; and test results were then compared to field pavement performance (1994–2009). While field cracks appeared at about the same time for both virgin and 30 percent RAP sections, the cracking progressed faster in RAP sections. Thus, resulting in rankings of field performance based on crack initiation that differ from rankings based on crack propagation; leading to different correlations with the OT results of respective asphalt mixtures. In conclusion, the OT appeared to be sensitive to the cracking performance differences (based on propagation definition) between the virgin and 30 percent RAP mixtures; thus, supporting the OT selection for implementation as part of the BMD approach.

The APA, OT, and FBF test criteria were based on field pavement performance and testing of asphalt mixtures locally available in the State. NJDOT, and in partnership with Rutgers University, built-up a database of performance test results on asphalt mixtures that was used for establishing a State-specific relationship between test results and field performance in New Jersey. The initial test criteria were based on the observed performance of the conventional and proprietary asphalt mixtures.

NJDOT has a history of good and poor performing asphalt mixtures. The PMS data provided useful means for comparing field pavement performance to laboratory test results. However, comparisons can also be as simple as general field observations and acknowledging when a field pavement section has or has not performed well.

It is critical to properly identify the cracking type and mechanism that a performance test is intended to address. For example, the FBF test is better at capturing the resistance of an asphalt mixture to crack initiation while the OT is mainly aimed at capturing the mixture's resistance to crack propagation. This should also be complemented with proper identification of field crack distresses and their associated modes of failure (e.g., fatigue cracking versus block cracking) along with adequate duration for in-service performance (e.g., longer in-service time is needed to capture differences in the resistance of asphalt mixtures to crack propagation).

Adjustments were made to performance test criteria based on the asphalt mixture location in the pavement structure and applied traffic level. Accordingly, air void levels representative of field density were selected for test specimens. The use and enclosure of additional performance tests also evolved over time. For example, the HPTO had initially an APA rut depth criterion due to concerns with potential rutting. Then, the HPTO specification was revised to include an OT cracking performance test and a number of cycles until failure criterion.

Finally, NJDOT has found field pavement performance from specific projects to be a great feedback and a robust validation of established performance test criteria for specifications. This feedback loop requires continuous communication and partnership between material, pavement design, and pavement management groups.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. NJDOT invested in new equipment and accessories in order to undertake performance testing. This involved additional resources to create new areas in the laboratories to accommodate equipment. All performance testing equipment are currently located in the central laboratory (Bureau of Materials– Bituminous Labs, Trenton, New Jersey) including an APA, FBF equipment with its own environmental chamber, standalone OT equipment, Marshall load frame on wheels utilized with an IDT jig, a compression machine (in the process to be retrofitted for IDT tests), and an AMPT utilized with OT jig.

Performance testing is only done at the central lab.

The challenge is to be able to find the resources to acquire equipment. Even when funds are available, procurement of the proper equipment requires time. Once the equipment manufacturer is identified, the procurement process can also be delayed due to capital equipment justification that is needed to compare the costs, benefits, and capabilities of different equipment (especially if the agency decided not to go with the least offered price). In some instances, NJDOT had to acquire equipment through research funds.

Additional costs are also involved in equipment necessary for sample fabrication and preparation (e.g., saw, compactor). Depending on equipment needed the cost can be significant (e.g., vibratory compactor for preparation of FBF specimens). Furthermore, NJDOT had to budget for

equipment verification, calibration and maintenance services. These recurring costs can be significant and have to be covered by NJDOT (such costs cannot be built into a project contract).

In 2015, a mini round robin study was conducted to compare test results of a newly acquired OT equipment from another manufacturer to those from the original device.⁽⁵⁵⁾ A statistical analysis comparing the test data from the two pieces of equipment was conducted. It should be noted that the new OT equipment was one of the first units built by the manufacturer, which created some challenges and issues with the equipment.

A total of three sub round robin studies were conducted using a single operator.⁽⁵⁸⁻⁶⁰⁾ The first sub round robin study was stopped mid-way through testing due to extremely poor test results. The results of the sub round robin 2 indicated that there were statistically significant differences between the average values from the two devices as well as differences in the resultant variability when testing a set of mixtures. After redesigning the environmental chamber and improving the cooling fan system, the test results generated from the sub round robin 3 showed that both machines were resulting in statistically equal average values and in very similar variances when testing the same mixture.

The study concluded that the new equipment can be used to determine the number of cycles until failure in accordance with the NJDOT B-10 test procedure.^(52,55) After the evaluation, the new unit was delivered to the NJDOT, and a two-day training course was held to familiarize the NJDOT engineers with the sample fabrication, preparation, testing, and data analysis.

Managing Resources. With the purchase of several performance tests and associated sample fabrication equipment, laboratory space becomes a challenge. For instance, NJDOT is in the process of reorganizing a laundry room for washing and drying dirty rags to fit the equipment for IDT testing. In another instance, a janitor closet was re-purposed for housing tack coat samples from field projects.

Finding laboratory space was a challenge.

Conducting Initial Training. Having an existing standard test method supported efficient implementation of performance tests for asphalt mixtures in NJDOT. While AASHTO standard test methods are available for APA and FBF, NJDOT had at first to rely on TxDOT test method for OT. Afterwards, in order to maintain uniformity in the test procedure over the years, NJDOT developed its own standard test method (NJDOT B-10) to determine the susceptibility of asphalt mixture specimens to fatigue or reflective cracking using the OT.

Some changes to the OT test method occurred during the effort of establishing a database of test results. While some of the changes led to reduction in the test variability, they negatively influenced the sensitivity of the OT to key asphalt mixture parameters. Accordingly, it was decided to maintain some of the initial test method instructions and reduce test variability by eliminating the high and low OT results and averaging and reporting the middle three test results.

Conducting Inter-Laboratory Studies. NJDOT pursued a round robin study for each of the mixture performance tests (i.e., APA, OT, FBF, and IDT) to determine single and multiple operator repeatability.⁽⁵⁸⁻⁶⁰⁾ Overall, this effort was a major undertaking.

- Round robin 1 (2016): Asphalt mixtures were tested in accordance with AASHTO T 340 in six different laboratories. Three of the laboratories utilized two-loaded wheel machines, while the remaining three laboratories utilized three-loaded wheel machines. Each laboratory was provided with four sets of asphalt mixtures that had different levels of rutting performance. For one of the mixture sets, the laboratories were provided three different subsets to address the interlaboratory variability of the APA test method. The testing results indicated a single and multiple laboratory COV of 10% and 20%, respectively. A comparison between two- and three-loaded wheel APA machines showed that both machines provide very similar test results. However, a lower variability was achieved with the three-wheel loaded machines (utilize 6 test specimens) when compared to the two-wheel loaded machines (utilize 4 test specimens).
- Round robin 2 (2017): asphalt mixtures were tested in accordance with NJDOT B-10 in five different research laboratories (four different equipment manufacturer types). Each laboratory was provided with three sets of asphalt mixtures that had different levels of cracking performance. For one of the mixture sets, the laboratories were provided three different subsets to address the interlaboratory variability of the OT test method. The testing results indicated a single and multiple laboratory COV of 24 percent and 30 percent, respectively. The study also determined the multiple laboratory COV for three different ranges of OT number of cycles until failure (i.e., COV of 18 percent for 300–600 cycles; COV of 42 percent for 800–1,900 cycles; and COV of 26 percent for cycles >2,000). It should be noted that all findings are based on testing five specimens for each asphalt mixture, eliminating the high and low value, and averaging the middle three results for reporting. Due to the observed variability in OT test results, the round robin revealed that an asphalt mixture designed for low level traffic would actually perform the same as for a higher traffic level. Accordingly, the HRAP OT requirements were revised to account for the test method repeatability and to differentiate between different levels of performance with no statistically equivalent overlap in test results.
- Round robin 3 (2018): a similar round robin study was completed for AASHTO T 321. An acceptable COV (~30 percent) was determined with BDWSC asphalt mixtures. All asphalt mixture samples were compacted by Rutgers University and shipped to the participating laboratories that were responsible for cutting and testing the specimens.
- Round Robin 4 (2019): asphalt mixtures were tested for high-temperature IDT strength and intermediate-temperature IDT cracking (ASTM D8225) by various asphalt plant quality control laboratories in New Jersey (9 different laboratories). Contrary to the prior three studies, the IDT round robin study prompted a much higher number of interested participants from the industry. Due to limitation in funds, the study selected 7 out of 13 industry partners to participate in the round robin. The round robin study involved a wide range of equipment types (5 test equipment setups) and technicians with some or minimal experience regarding the test procedures. The testing results of high-temperature IDT indicated a single and multiple laboratory COV for triplet specimens of 8.2 percent and 11.8 percent, respectively. The single and multiple laboratory COV for intermediate-temperature IDT were 15.2 percent and 23.0 percent, respectively.

Annual round robin studies were used to determine repeatability. They also allowed users to gain trust and comfort with the performance tests.

In all round robin studies, participating laboratories were provided clear instructions on sample handling and testing procedures. Laboratories were supplied with a Microsoft Excel reporting sheet for each of the test methods. Rutgers University analyzed and reported all test results from the different participating laboratories.

In general, the round robin studies were very beneficial and helped NJDOT to further gain trust and comfort with performance tests. The round robin studies were all conducted under the NJDOT PSP that is funded by the SP&R Program. Having such an established program with available resources greatly supported the overall effort to advance performance tests into practice.

Task 5: Establishing Baseline Data.

Conducting Benchmarking studies. Rutgers University established a large database of performance test results on an array of asphalt mixtures used throughout the State. These asphalt mixtures included different aggregate blend gradations, NMAS, PG of asphalt binder, asphalt mixture type (e.g., dense-graded, SMA, etc.), binder content, production temperatures, silo storage time, etc. This database was used as needed to validate the performance test results of other types of asphalt mixtures. Continuous communication and knowledge sharing with NJDOT allowed adjustments to be made during the performance testing period.

A large database of performance test results was established for a wide variety of mixtures used throughout the State.

While this effort is significant, testing asphalt mixtures in an incremental manner helped in undertaking this task in an efficient and productive means. Performance testing of local materials was highly important for NJDOT as it helped identifying underperforming asphalt mixtures.

Conducting Shadow Projects. At first, few contractors were interested and there was trepidation and opposition due to contractors' lack of understanding regarding the "performance" NJDOT was looking for. Industry primarily cared about volumetric, in-place air voids, and smoothness as these are the factors that control production and pay factors. However, even when meeting these parameters, asphalt mixtures can still rut and crack. Thus, initially, there was a disconnect that needed to be bridged. Additionally, several contractors were not experienced with performance testing and expressed concerns with failing test requirements. At one point, there was a push from some members of the industry to stop the use of performance testing for specialty asphalt mixtures. It took time, dialogue, education, and partnering to get the performance tests implemented on field projects. Having a champion from the NJDOT along with a trusted partner from the industry who is willing to work with the agency on improving the process, accelerated the learning curve and made implementation possible.

In general, there was no formal implementation plan. Early on, specialty asphalt mixtures were implemented on projects with no penalties being imposed for plant asphalt mixtures failing performance specifications during production. Thus, providing contractors the opportunity to gain experience and time to become familiar and comfortable with the process. Furthermore, the

Shadow projects allowed contractors to gain experience and become familiar with performance tests.

sampling frequency was initially low and around 10,000 tons of placed asphalt mixtures to allow for time and to gain experience with testing and the process.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. The sensitivity of a performance test results to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), air voids, and aging is an important factor for NJDOT. 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. A formal study to assess, in particular, the influence of changes in volumetric and other properties and their relationship to the performance of the asphalt mixtures was not conducted. However, a database was developed with the benchmarking study in subtask 5.2. This information was used to analyze adjustments needed to improve results from the various performance tests.

Task 6: Specifications and Program Development.

Developing Pilot Specifications and Policies. In the latest specifications, NJDOT requires the asphalt mixture producer to sample and test for volumetric properties at the plant for each 700 tons of specialty asphalt mixture. The contractor is also required to provide NJDOT with gyratory compacted specimens and boxes of loose asphalt mixtures. The compacted specimens are used for performance testing and loose asphalt mixture is used to determine the maximum specific gravity of the asphalt mixture. While testing for volumetric properties happens in NJDOT regions (at the asphalt plant by personnel from NJDOT districts and contractors' quality control technicians), performance testing is conducted by NJDOT at the central laboratory in Trenton, New Jersey.

The first sample is taken during the construction of the test strip. Thereafter, every lot (HPTO or HRAP), every second lot (BDWSC or BRIC), or every fifth lot (BRBC) is sampled. Performance testing is conducted at the rate of one sample for each 1,400 tons of BDWSC, 3,500 tons of

Detailed specifications were prepared which included the use of a test strip and field-testing frequencies.

HPTO, 1,400 tons of BRIC, 3,500 tons of BRBC, and 700 tons of HRAP (rates of testing can be modified by ME). The performance testing results will be included in the first lot if the test strip was done within the project limits and the results were acceptable.

If a sample does not meet the criteria for performance testing as specified in table 11, a pay adjustment will be assessed (HPTO or HRAP) or production may be stopped until corrective action has been taken. Removal and replacement of a lot may be required if the BRIC exceeds the respective APA criterion or if the HRAP fails to meet requirements for both APA and OT. Thus, a quick turnaround of performance test results was critical during production, in particular for HPTO and HRAP where results are tied to a pay factor. Equipment calibration and proper documentation are a must in case of any disputes by contractors.

In comparison to asphalt mix design criteria, a slightly higher APA test criterion is implemented on plant-produced asphalt mixtures for HPTO and BRIC (HPTO: 5 mm relative to 4 mm rut depth in design; and BRIC: 7 mm relative to 6 mm rut depth in design). Similarly, the minimum OT number of cycles under failure was reduced from a minimum of 700 cycles during asphalt

mix design to a minimum of 650 cycles during plant production. These changes stemmed from the observed pavement performance, where plant-produced asphalt mixtures that slightly failed the asphalt mix design test criteria still performed well in the field. Based on a recent study on the laboratory performance of plant-produced asphalt mixtures, the minimum OT requirements for BRIC will be increasing in 2020 for both the design and production performance testing

Final Analysis and Specification Revisions. Implementation of performance testing for specialty mixtures has been successful. There is now interest in using them for acceptance. Requiring performance testing during production and at an increased frequency of sampling required NJDOT staff to work overtime (added cost to the agency) in order to keep up with sample preparation, testing, data analysis, and test reports. Performance testing required longer

Performance testing was successfully implemented for mix design and there is now interest in using them for acceptance.

working hours that involved the readiness, approval, and adjustment of the staff to the new schedule. Having extra sample molds and programmable conditioning ovens would help to speed up the process; however, that option was not viable to NJDOT because of electricity issues in the aging building where performance tests are being housed.

Another challenge that NJDOT faced during production is the breakdown of a specific performance test equipment with no access to a backup equipment or a quick repair service. In some instances, repairing a malfunctioning equipment requires issuing a purchase order that can take up to three months to be executed. Thus, there is a need to develop good relationships with equipment suppliers and ensure they can provide quick service in emergency situations. Through their existing contract, NJDOT relied on Rutgers University's support with the overflow of performance testing when NJDOT is inundated with test specimens or when an equipment is down.

Industry has also expressed interested in having IDT performance testing on pilot projects as part of the project bid. Implementing proper performance tests within a BMD approach allowed contractors to be creative and see the benefits of the tests. However, contractors are looking for information on recommended changes to asphalt mixtures to bring them into compliance. These changes could be different than those that contractors make using traditional volumetric-based mix designs. This would require training and certification of asphalt plant technicians and operators from around the State.

There is interest in exploring the use of surrogate testing.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. Trained technicians on the procedures and analysis of test results are necessary. Whenever needed or requested, Rutgers University hosted laboratory demonstration visits or provided training (hands-on) to familiarize the NJDOT engineers, contractors, or consultants with sample fabrication, preparation, testing, and data analysis. Nonetheless, Rutgers University was in continuous communication and maintained engaged conversations with NJDOT.

NJDOT faced a challenge with the loss of institutional knowledge due to a recent retirement of staff who had been involved in the implementation effort of performance specifications for

asphalt mixtures. Rutgers University played a major role in assuring continuity and preserving historical knowledge.

Task 8: Initial Implementation.

All specialty asphalt mixtures comprised on average about 10 percent of the total asphalt tonnage placed in the State (figure 13). The use of specialty asphalt mixtures steadily increased from 5.1 percent in 2015 to as much as 16.8 percent in 2018. In 2019, specialty asphalt mixtures comprised 8.3 percent of the total asphalt tonnage placed. The observed drop in the percent use of specialty asphalt mixtures last year is mainly attributable to project prioritization and selection process (resurfacing projects not continuously ranking high in the process) in conjunction with delays in the procurement process (complexity of requirements stipulated in the procurement rules pushed back some of the projects until next year). Among all five specialty asphalt mixtures, HPTO has been used the most. The selection of a specialty asphalt mixture for the pavement structure in question has been generally based on the accrued experience of senior staff throughout the years. With the use of specialty asphalt mixtures being more frequent and on a regular basis, a project selection document that provides guidance to junior staff is considered critical and timely to ensure knowledge and expertise continuity within NJDOT. In an on-going effort, NJDOT has been working on the development of a pavement design and policy manual. NJDOT has been following the 1993 AASHTO Design Method and is in the process of transitioning to the AASHTOWare Pavement ME Design.

NJDOT effort started on the process of developing a pavement design and policy manual in 2016. Some internal design guidance and flowcharts on mix type selection were developed over time but these were never compiled into one comprehensive manual. Early 2019, NJDOT procured proposals from consultants to assist as part of the department wide “augmentation” effort. Also, in 2019, they met with FHWA as part of a national effort to update current federal policies and procedures on pavement design, at which time FHWA offered to assist with NJDOT pavement design and policy manual. This collaborative effort is between NJDOT, FHWA and their consultant.

NJDOT’s ultimate plan is to implement BMD approach for its dense-graded asphalt mixtures. Some preliminary steps and timeframes on how NJDOT can move to using performance tests on all of its asphalt mixtures were developed. The draft 5-year implementation plan is currently being evaluated and, once ready, it will be executed. It should be noted that the 5-year timeline can vary based on staffing and pandemic situation.

The initial goal was to use performance testing in the implementation of specialty mixtures, about 10 to 15 percent of the program. Once accomplished, the next step will be implementation for dense-graded asphalt

OBSERVED BENEFITS

Pavement performance improved as documented by the PMS as shown in figure 15. In 2006 the percent of system lane miles in good condition was 12 percent. This increased to 40 percent in 2019.

In addition to the improvement in the overall pavement network, specific studies were done on the performance of HPTO and BRIC. A 2016 PSP study evaluated the field performance of pavement sections containing HPTO and BRIC using the NJDOT PMS. Pavement performance curves in terms of the SDI parameter as a function of time were developed. A pavement is considered deficient when the SDI is less than or equal to 2.4.

The study showed that the HPTO would last 10–13 years when placed on pavements with an existing SDI greater than 2.4. The projected life of HPTO was reduced to ~5 years when placed on pavements with an existing SDI less than 2.4.⁽⁶¹⁾ On the other hand, the use of BRIC in general improved the projected pavement life. The use of an SMA overlay with BRIC improved the projected pavement life by over 10 years in comparison to a composite pavement with a dense-graded asphalt mixture with no BRIC.⁽⁶¹⁾

The use of performance tests with specialty mixtures was a significant reason for the overall improvement of the road network.

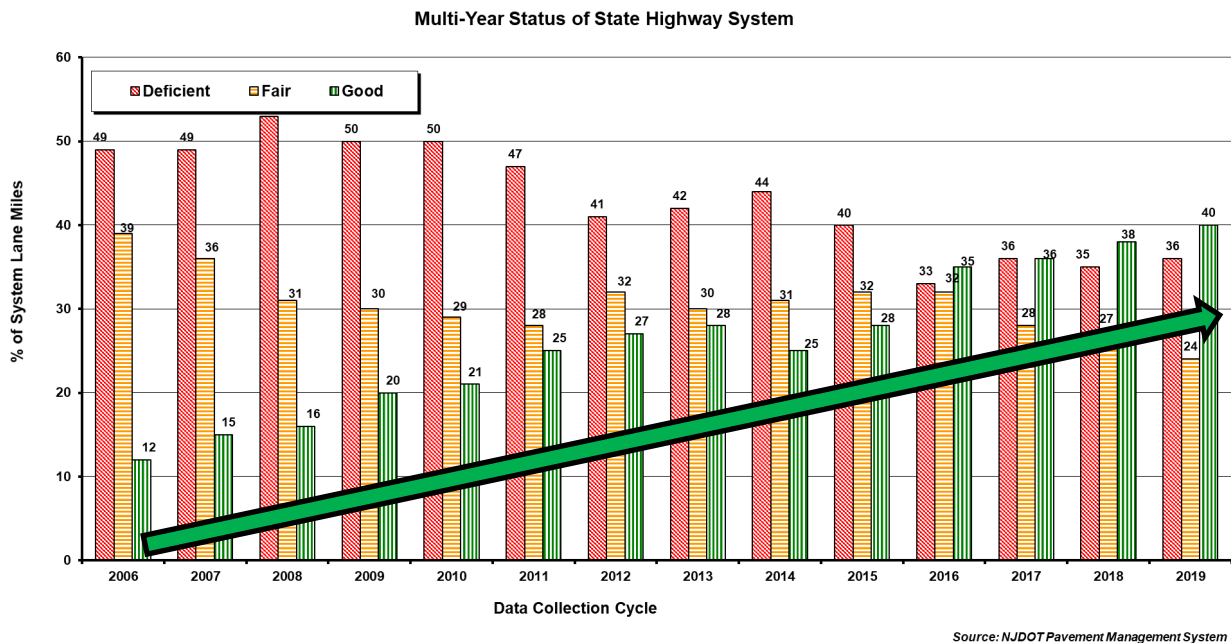


Figure 15. Chart. NJDOT’s Improvement of Overall Quality of Road Network.

In summary, both HPTO (when placed over a pavement with SDI > 2.4) and BRIC (with SMA overlay) showed very good field performance that considerably exceeded the performance of conventional NJDOT asphalt mixtures. Thus, delaying the next rehabilitation or reconstruction activity and leading to significant life cycle cost savings in terms of both agency and user costs.

The use of performance testing allowed contractors to utilize innovative and recycled materials (e.g., RAP, recycling agents [RAs], PG of asphalt binders) in order to produce asphalt mixtures that are in compliance with NJDOT specifications; including asphalt binder suppliers which had to formulate specialty asphalt binders to help with performance requirements. Furthermore, the traditional volumetric-based mix design did not provide optimum performance for asphalt mixtures with high RAP content. Performance testing helped designing asphalt mixtures with high RAP that resulted in ultimate performance against primary modes of distress (i.e.,

durability/cracking and rutting); thus, allowing for the production of economical and environmentally friendly asphalt mixtures without jeopardizing performance.

FUTURE DIRECTION

Recently, NJDOT, in collaboration with Rutgers University, started to explore the use of the high-temperature IDT strength and the intermediate-temperature IDT Cracking test as a surrogate test during production. Based on test results of asphalt mixtures from Rutgers University, the IDT strength and IDT Cracking were found to correlate well with the APA rut depth and OT number of cycles until failure, respectively. These correlations are in the process of being verified by NJDOT. This effort mainly stemmed from the need to reduce the workload of the NJDOT staff, to accelerate the turnaround time for performance test results during production, and to provide a performance test that could be conducted by the asphalt plants quality control laboratories with minimum financial investment and required training. The two IDT-based index-based performance test methods involve a reduced time for specimen fabrication, preparation (including reduced number of specimens needed), testing, and data analysis. Thus, making them viable for routine use in a BMD process and acceptance.

Additionally, NJDOT's ultimate plan is to implement BMD approach for its dense-graded asphalt mixtures. Some preliminary steps and timeframes on how NJDOT can move to using performance tests on all of its asphalt mixtures were developed. The draft 5-year implementation plan is currently being evaluated and, once ready, it will be executed. It should be noted that the 5-year timeline can vary based on staffing and pandemic situation.

CHAPTER 7 VIRTUAL SITE VISIT: TXDOT (AUGUST 2020)

INTRODUCTION

TxDOT is currently responsible for maintaining approximately 197,000 lane-miles of highway infrastructure. In fiscal year 2019, TxDOT placed about 16 million tons of asphalt mixture. The TxDOT standard asphalt mixtures are specified in standard specifications Item 341 Dense-Graded Hot-Mix Asphalt (DG HMA) and Item 344 Superpave Mixtures (SP).⁽⁶²⁾ Item 341 and Item 344 are used for approximately 35 and 45 percent of the asphalt mixtures placed by TxDOT, respectively. The primary differences in the specifications are Item 341 has historically relied on Texas Gyrotory Compaction and Item 344 requires Superpave Gyrotory Compaction, as well as has higher VMA requirements leading to higher typical binder contents than Item 341.

Specialty asphalt mixtures account for the remainder 20 percent of the asphalt mixtures placed by TxDOT and have been used for more than 15 years. Specialty asphalt mixtures are specified in standard specifications Item 342 Permeable Friction Course (PFC), Item 346 Stone-Matrix Asphalt (SMA), Item 347 Thin Overlay Mixtures (TOM), and Item 348 Thin Bonded Friction

Performance testing allowed for the creation of specialty mixtures which addressed specific pavement distresses. Specialty mixtures were about 20 percent of the program.

Courses (TBFC).⁽⁶²⁾ TxDOT has a special specification (SS) for the crack attenuating mixture (CAM) that is designed to reduce reflective cracking in asphalt mixture overlays (SS 3000).⁽⁶³⁾ A summary of the standard and specialty asphalt mixtures along with their applications is shown in table 31.

TxDOT specifications for DG HMA and SP mixtures currently require the HWTT for rutting performance evaluation. On the other hand, TxDOT specifications for specialty asphalt mixtures require, in addition to the HWTT, the OT for cracking performance evaluation.

In 2015, as part of TxDOT Project 0-6742 *Performance Tests for Thin Asphalt Layers*, guidelines for project selection, design, and construction of thin overlays were developed and published.⁽⁶⁴⁾ The thin asphalt overlays are laid at 1.0 to 0.5 inches thick and include the fine PFC Type F (PFC-F), fine SMA Type F (SMA-F), TOM, and CAM.

RAP is widely used and RAS is sometimes used in asphalt mixtures in Texas. With the increase use of such materials, SP mixtures started to experience premature failure or did not perform as originally intended. Accordingly, TxDOT in coordination with the industry started to

After the successful use of BMD with specialty mixtures, performance tests were used for dense-graded mixtures to improve performance with recycled materials.

examine the use of performance tests and the BMD on SP surface mixtures. A new TxDOT SS 3074 Superpave Mixtures – Balanced Mix Design was developed to produce asphalt mixtures with satisfactory volumetric and mechanical performance.⁽⁶³⁾ The SS 3074 aims at improving asphalt pavement performance through a responsible use of recycled materials in asphalt mixtures. The HWTT and OT results are implemented in the SS 3074 to assess the stability and durability of asphalt mixtures during the design process.

Table 31. Asphalt Mixture Types Used by TxDOT.

Specifications	Specialty Asphalt Mixture	Typical Applications
Item 341 Dense-Graded Hot-Mix Asphalt (DG HMA)		<ul style="list-style-type: none"> Used in base, intermediate, or surface layers. High to low volume (demand) roadways. New and rehabilitation construction.
Item 342 Permeable Friction Course (PFC)	X	<ul style="list-style-type: none"> Used as surface layer. High speed roadway (posted speed limit ≥ 45 mph). Optimize safety and comfort characteristics of the roadway. New and rehabilitation construction.
Item 344 Superpave Mixtures (SP)		<ul style="list-style-type: none"> Used in base, intermediate, or surface layers. Medium to high volume (demand) roadways. New and rehabilitation construction.
Item 346 Stone-Matrix Asphalt (SMA)	X	<ul style="list-style-type: none"> Used in intermediate or surface layers. High volume (or high demand) roadways. New and rehabilitation construction.
Item 347 Thin Overlay Mixtures (TOM)	X	<ul style="list-style-type: none"> Used as surface layer for preservation of existing pavements. High to low volume roadways. High performance overlay.
Item 348 Thin Bonded Friction Courses (TBFC)	X	<ul style="list-style-type: none"> Used as surface layer. High speed roadway (posted speed limit ≥ 45 mph). Optimize safety and comfort characteristics of the roadway. New and rehabilitation construction.
SS 3000 Crack Attenuating Mixture (CAM)	X	<ul style="list-style-type: none"> Used as an interlayer. High to low volume (demand) roadways. Rehabilitation construction.
SS 3074 Superpave Mixtures – Balanced Mix Design (SP – BMD)		<ul style="list-style-type: none"> Used as surface layer. High to low volume roadways. New construction and overlays.

Recently, TxDOT initiated a large effort in partnership with industry and academia to revise and further develop the SS 3074 for SP surface mixtures with RAP. This involves the placement of ~12 test projects (or referred to as demonstration projects) between 2019 and 2021 by contractors of the Texas Asphalt Pavement Association (TXAPA) around the State. Each test project will have 3 to 4 test sections; a control section and 2–3 test sections with BMDs focusing on key variables such as RAs, aggregate gradation, and asphalt binder source and grade. Accordingly, TxDOT established Interagency Cooperation Contracts (IACs) with the Texas A&M University—Texas A&M Transportation Institute (TTI), University of Texas at Austin (UTA)—Center for Transportation Research (CTR), and University of Texas at El Paso (UTEP)—Center for Transportation Infrastructure Systems (CTIS). The three universities are providing and supporting TxDOT with asphalt mix designs and laboratory testing and analysis. The outcome of this effort is a specification and related test methods for design and quality acceptance, and performance thresholds to produce a practical method to engineer each unique materials combination to realize substantial economic and environmental benefits without forfeiting a balanced engineering performance.

BMD APPROACH

TxDOT developed a special specification for BMD of surface asphalt mixtures: “Special Specification 3074 for Superpave Mixtures – Balanced Mix Design.” Figure 16 shows a flowchart of the overall BMD that highlights the major steps for undertaking an SP – BMD according to TxDOT specifications. The requirements for volumetric design and performance testing for specialty asphalt mixtures and SP – BMD are summarized in table 32 and table 33. Performance testing requirements are provided as a function of the high temperature asphalt binder PG; thus, taking into consideration both climate and traffic conditions.

The TxDOT’s BMD for designing asphalt mixtures and approving JMFs follows Approach A *Volumetric Design with Performance Verification*. At this time, there are a couple of goals: 1) use the BMD approach on 80 percent of the mixtures, and 2) use approach C or D. Starting with Approach A on pilot projects is the first step. The SP – BMD asphalt mixture is designed at 50 gyrations (N_{design}) to a target laboratory-molded density of 96.0 percent. However, adjustments can be made to the N_{design} value when shown on the plans, specification, or mutually agreed between TxDOT and the contractor. The N_{design} level may be reduced to no less than 35 gyrations at the contractor’s discretion (a range of 35–100 gyrations).

The contractor can provide with the mix design the HWTT results performed by an approved laboratory from the TxDOT’s material producer list (MPL) or can request TxDOT to perform the HWTT by providing the laboratory mixture. The contractor will also provide laboratory mixture to TxDOT to perform OT. The HWTT and OT results on the laboratory mix design is provided to the contractor within 10 working days.

Having laboratories approved on an MPL to perform HWTT helped State DOT in maintaining acceptable workload level.

TxDOT will verify and approve all mix designs (JMF1) before the contractor can begin production. JMF1 is the original laboratory mix design used to produce the trial batch. The JMF1 is verified based on plant-produced asphalt mixture from the trial batch. If the asphalt mixture produced using the JMF1 meets the volumetric and performance requirements (HWTT and OT) for the SP – BMD, a correlation between the OT (Tex-248-F) and IDEAL Cracking Tolerance test (IDEAL-CT) (Tex-250-F) will then be established.^(65,66) If the plant-produced asphalt mixture (JMF1) fails any of the criteria, the contractor has to redesign and resubmit the asphalt mixture for JMF approval following the same process.

To perform a correlation between the OT and the IDEAL-CT, laboratory asphalt mixture is provided to TxDOT at the OBC submitted for JMF1 and at binder contents 0.5 percent above and below the OBC. The performance tests will be conducted by TxDOT or by an approved laboratory from the TxDOT’s MPL to establish an acceptable limit for IDEAL-CT. The IDEAL-CT test is also performed on the trial batch mixture (i.e., plant-produced asphalt mixture) to validate the correlation between the OT and IDEAL-CT. The correlation is expected to be established for each project and on a mixture by mixture basis. TxDOT is allowed 10 working days to provide the contractor with HWTT, OT, and IDEAL-CT results on the trial batch.

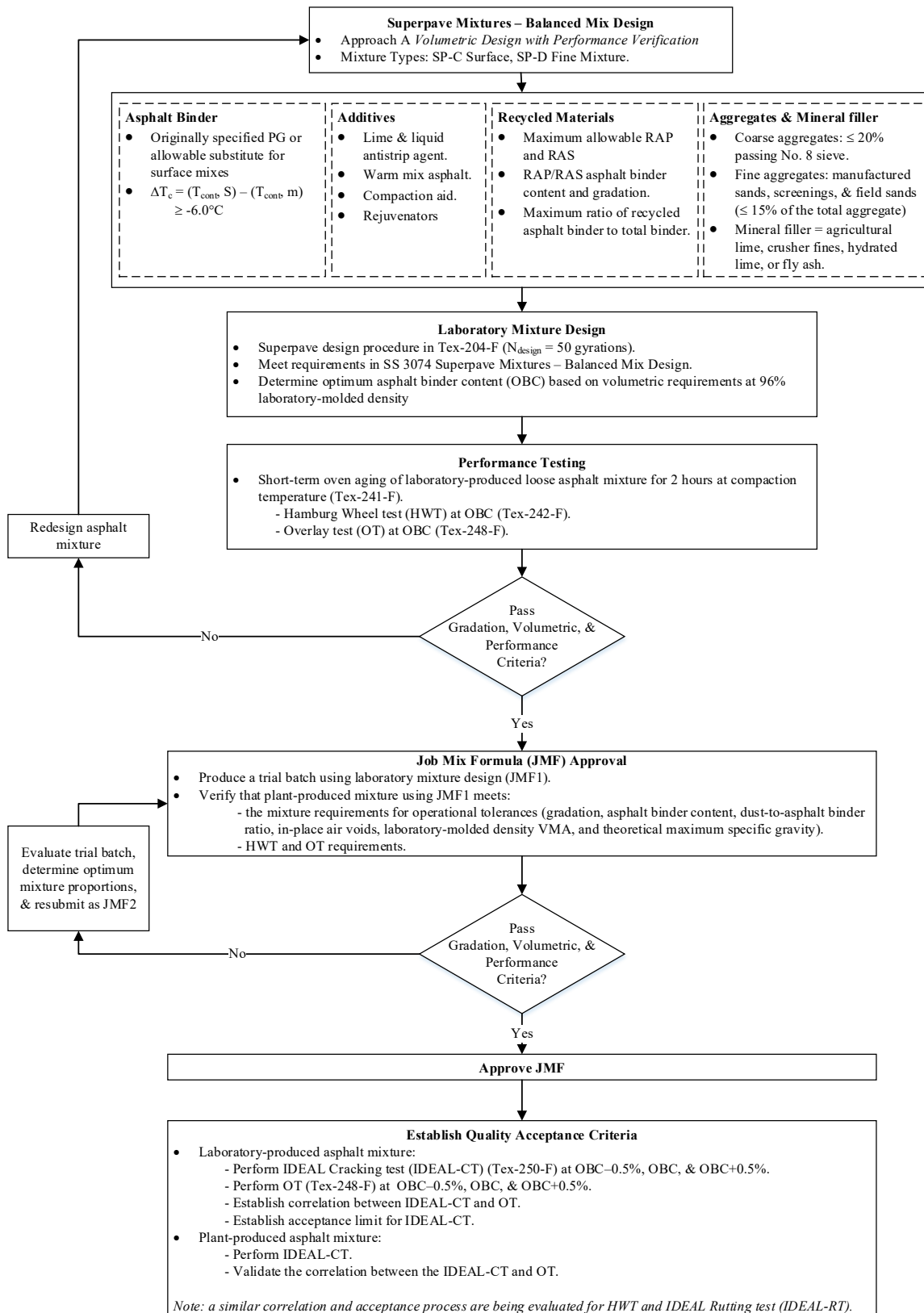


Figure 16. Chart. Overview of TxDOT’s BMD approach for SP – BMD of surface mixtures.

Table 32. TxDOT Specifications for Volumetric Design Requirements.

Mixture Type		Binder Content (%)	Target Lab-Molded Density (%)	VMA (Minimum %) ^s						Dust-to-Binder Ratio [#]	Drain-down (%)
				Nominal Maximum Aggregate Size (NMAS) (mm)							
				37.5	25	19	12.5	9.5	4.75		
DG HMA	A, B, C, D, or F	–	96.5*	12.0	13.0	14.0	15.0	16.0	–	–	–
SP Mixtures	SP-A, SP-B, SP-C, or SP-D	–	96.0	13.0	14.0	15.0	16.0	–	–	0.6–1.6	
PFC	Fine (PFC-F)	6.0–7.0	≤ 78.0	–	–	–	–	–	–	–	≤0.1%
	Coarse (PFC-C)	6.0–7.0	≤ 82.0	–	–	–	–	–	–	–	≤0.1%
	Fine (PFCR-F)	8.0–10.0	≤ 82.0	–	–	–	–	–	–	–	≤0.1%
	Coarse (PFCR-C)	7.0–9.0	≤ 82.0	–	–	–	–	–	–	–	≤0.1%
SMA	SMA Mixtures	6.0–7.0	96.0	–	–	–	17.5	17.5	–	–	≤0.1%
	SMAR Mixtures	7.0–10.0	96.0	–	–	–	19.0	19.0	–	–	≤0.1%
TOM	Coarse (TOM-C)	≥ 6.0	97.5*	–	–	–	–	16.0	–	–	≤0.2%
	Fine (TOM-F)	≥ 6.5	97.5*	–	–	–	–	16.5	–	–	≤0.2%
TBFC	Fine (PFC-F)	6.0–7.0	≤ 78.0	–	–	–	–	–	–	–	≤0.1%
	Coarse (PFC-C)	6.0–7.0	≤ 82.0	–	–	–	–	–	–	–	≤0.1%
	Coarse (PFCR-C)	7.0–9.0	≤ 82.0	–	–	–	–	–	–	–	≤0.1%
	TBWC-Type A	5.0–5.8	≤ 92.0	–	–	–	–	–	–	–	≤0.1%
	TBWC-Type B	4.8–5.6	≤ 92.0	–	–	–	–	–	–	–	≤0.1%
	TBWC-Type C	4.8–5.6	≤ 92.0	–	–	–	–	–	–	–	≤0.1%
CAM	Fine Mixture	≥ 7.0	98.0	–	–	–	–	–	17.0	≤ 1.4	–
SP – BMD	SP-C Surface	–	96.0	–	–	15.0	–	–	–	0.6–1.6	–
	SP-D Fine Mixture	–	96.0	–	–	–	16.0	–	–	0.6–1.6	–

–Not applicable.

^sUses effective specific gravity of the aggregate (G_{se}) and not bulk specific gravity of the aggregate (G_{sb}).

[#]Defined as percent passing No. 200 sieve divided by binder content.

*Texas gyratory compactor.

In comparison to AASHTO M 323 and AASHTO R 35, TxDOT implemented the following key modifications to their volumetric design criteria (table 32 to table 34):

- Specified 50 gyrations for design and acceptance of all asphalt mixtures including the standard and specialty mixtures.
- Specified a minimum or a range of binder content for specialty asphalt mixtures (i.e., PFC, SMA, TOM, TBFC, and CAM). In order to avoid bleeding of the asphalt mixture, and with the exception of CAM, a draindown requirement was also specified (Tex-235-F).⁽⁶⁶⁾
- For the virgin asphalt binder, the difference in critical temperatures for low temperature testing (ΔT_c) based on creep stiffness ($T_{cont, S}$) and m-value ($T_{cont, m}$), calculated as $\Delta T_c = (T_{cont, S}) - (T_{cont, m})$, must be greater than or equal to -6.0°C . The critical temperature is defined as the temperature at which the test parameter is equal to the specification limit.
- Increased the VMA requirement by 1–4 percent for DG HMA, SP Mixtures, SMA, TOM, CAM, and SP – BMD. However, VMA is calculated using the effective specific gravity of the aggregate (G_{se}).
- Reduced the design VMA by 0.5 percent for plant-produced asphalt mixtures (in comparison to laboratory-produced asphalt mixtures).
- Excluded the requirement for VFA for all asphalt mixtures.

- Excluded the dust-to-binder ratio requirement; except in the case of CAM and SP – BMD for which the upper limit was increased by 0.2 and 0.4 percent, respectively. It should be noted that the dust-to-binder ratio is defined as percent passing No. 200 sieve divided by total binder content.
- Increased the maximum allowable fractured RAP in surface mixtures from 20 percent (DG HMA and SP) to 35 percent (SP – BMD).

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by allowing more binder into the mixture without jeopardizing its resistance to rutting (the higher the VMA, the higher the binder content for a given air void level).

Table 33. TxDOT Specifications for Mix Design Performance Testing Requirements.

Mixture Type		High-Temperature Asphalt Binder PG	HWTT at 50°C		OT [§]			IDT (dry), psi [§]
			Passes at 12.5 mm Rut Depth	Rut Depth at 20,000 passes	Number of Cycles	CFE, inch-psi	CPR	
DG HMA (Item 341)	A (Coarse Base), B (Fine Base), C (Coarse Surface), D (Fine Surface), F (Fine Mixture)	PG 64 or lower	≥ 10,000	–	–*	–	–	85–200
		PG 70	≥ 15,000	–	–*	–	–	85–200
		PG 76 or higher	≥ 20,000	–	–*	–	–	85–200
SP Mixtures (Item 344)	SP-B (Intermediate), SP-C (Surface), or SP-D (Fine Mixture)	PG 64 or lower	≥ 10,000	–	–*	–	–	85–200
		PG 70	≥ 15,000	–	–*	–	–	85–200
		PG 76 or higher	≥ 20,000	–	–*	–	–	85–200
PFC (Item 342)	Fine (PFC-F)	PG 76	≥ 10,000	–	≥ 200	–	–	–
	Coarse (PFC-C)	PG 76	Report only	–	Report only	–	–	–
	Fine (PFCR-F)	A-R	Report only	–	Report only	–	–	–
	Coarse (PFCR-C)	A-R	Report only	–	Report only	–	–	–
SMA (Item 346)	SMA	–	–	≤ 12.5 mm	≥ 200	–	–	–
	SMAR	–	–	≤ 12.5 mm	≥ 200	–	–	–
TOM (Item 347)	Coarse (TOM-C) or Fine (TOM-F)	PG 70	≥ 15,000	–	≥ 300	–	–	≤ 200
		PG 76	≥ 20,000	–	≥ 300	–	–	≤ 200
TBFC (Item 348)	Fine (PFC-F)	PG 76	≥ 10,000	–	≥ 200	–	–	–
	Coarse (PFC-C)	PG 76	Report only	–	Report only	–	–	–
	Coarse (PFCR-C)	A-R	Report only	–	Report only	–	–	–
	Thin Bonded Wearing Course (TBWC)	Type A	Report only	–	Report only	–	–	–
		Type B	Report only	–	Report only	–	–	–
Type C		Report only	–	Report only	–	–	–	
CAM (SS 3000)	Fine Mixture	PG 64 or lower	≥ 10,000	–	≥ 750	–	–	85–200
		PG 70	≥ 15,000	–	≥ 750	–	–	85–200
		PG 76 or higher	≥ 20,000	–	≥ 750	–	–	85–200
SP – BMD (SS 3074) [#]	SP-C (Surface) or SP-D (Fine Mixture)	PG 64 or lower	≥ 10,000	–	–	≥ 1.0	≤ 0.45	85–200
		PG 70	≥ 15,000	–	–	≥ 1.0	≤ 0.45	85–200
		PG 76 or higher	≥ 20,000	–	–	≥ 1.0	≤ 0.45	85–200

–Not applicable.

[§]CFE= Critical Fracture Energy; CPR=Crack Progression Rate, IDT according to Tex-226-F.

*For informational only when requested or shown in the plans during the first week of production.

[#]When HWTT and OT meet the requirements, a correlation is established between OT and IDEAL-CT (Tex-250-F).

Table 34. Summary of TxDOT Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Mixture Type					
	PFC	SMA	TOM	TBFC	CAM	SP – BMD
Number of Design Gyration (N_{des})	↓	↓	↓	↓	↓	↓
Density at N_{des}	↓	↔	↑	↓	↑	↔
Density at Maximum Number of Gyration (N_{max})	–	–	–	–	–	–
Design Binder Content	Range	Range	Min	Range	Min	–
Voids in Mineral Aggregate (VMA)*	–	↑	↑	–	↑	↑
Voids Filled with Asphalt (VFA)	–	–	–	–	–	–
Dust-to-binder ratio	–	–	–	–	↑ UL	↑ UL
Draindown (%)	Max	Max	Max	Max	–	–
HWTT Passes at 12.5 mm Rut Depth	Min/R	–	Min	Min/R	Min	Min
HWTT Rut Depth at 20,000 Passes	–	Max	–	–	–	–
OT Number of Cycles	Min/R	Min	Min	Min/R	Min	–
OT CFE	–	–	–	–	–	Min
OT CPR	–	–	–	–	–	Max

–Not applicable or not specified; Min=minimum; Max=maximum; R=report only; ↔=no change to requirement; ↓=decreased; ↑=increased; ↑ UL=increased upper limit

*Uses Gse and not Gsb.

IMPLEMENTATION PROCESS OF BMD

Task 1: Motivations and Benefits of BMD.

The motivations for implementation of BMD in Texas were primarily two-fold: 1) there was an immediate need to address the observed premature failures of asphalt pavements as a result of the use of recycled materials in asphalt mixtures; and 2) there was a desire to use higher quantities of RAP that allowed for economical and environmental-friendly asphalt mixtures.

Task 2: Overall Planning.

Identification of Champions. Internally, there was a champion in the Materials and Tests Division (MTD) that led the communication and coordination with the various stakeholders. This was a monumental effort.

Establishing a Stakeholders Partnership. TxDOT has been leading and investing significantly in the process to develop and implement a BMD for its standard asphalt mixtures. This stems from TxDOT’s successful experience with specialty asphalt mixtures and the immediate need to address premature failure of asphalt mixtures with RAP. In a major undertaking, TxDOT funded in 2019 an IAC with multiple Texas universities to implement the concept of BMD for Superpave asphalt mixtures with RAP. This is a large, coordinated effort between TxDOT

(including districts), contractors (TXAPA is engaged in this effort), additives manufacturers and suppliers, and academia.

Doing Your Homework (Identifying the Issues, Identifying Resources, and Reviewing Literature).

TxDOT has a long history of using the HWTT and OT for evaluating and screening asphalt mixtures with good and poor rutting and cracking resistance, respectively. TxDOT has

Performance tests were implemented in a phased manner. The HWTT was implemented in 2004 and the OT was implemented in 2014.

successfully used the HWTT in their mix design selection for several years, and the test has been included in their standard specifications since 2004. TxDOT has also had success using performance tests with their specialty asphalt mixtures, which now accounts for approximately 20 percent of their total

asphalt mixtures. All HWTT results are properly stored in a database that is maintained by TxDOT. A similar database exists for OT results of asphalt mixtures from TX. The OT has been implemented in the standard specifications since 2014. Prior to that, the OT was used by TxDOT in SS for specialty asphalt mixtures (e.g., SMA).

Establishing Goals. TxDOT envisions using BMD for all of its standard asphalt mixtures using a stepwise approach (phased-in implementation). The BMD is primarily founded on the HWTT and OT, with which TxDOT has had a long history of use. The implementation of the BMD for acceptance required the use of surrogate tests that are simple and quick to run.

The initial goal for use of BMD was with specialty mixtures and it is now evolving to include dense-graded mixtures.

Identifying Available External Technical Information and Support.

TxDOT established IACs with the Texas A&M University—TTI, UTA—CTR, and UTEP—CTIS. The three universities are providing and supporting TxDOT with asphalt mix designs and laboratory testing and analysis.

IACs with three universities were a key to success.

Developing an Implementation Timeline. TxDOT has successfully used the HWTT in their mix design selection for several years, as the test has been included in their standard specifications since 2004. TxDOT has also had success using performance tests with their specialty asphalt mixtures, which now accounts for approximately 20 percent of their total asphalt mixtures. Successes in this area allowed the consideration of performance testing and BMD to evolve into the Superpave surface mixtures. Performance testing has been part of TxDOT projects. TxDOT is now developing the BMD approach for selecting the OBC for all of TxDOT’s asphalt mixtures based on the HWTT and OT results. From 2019 to 2021 about 20 projects will be piloted based on volunteers from the districts and contractors.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. There was an immediate need to address the observed premature failures of asphalt pavements as a result of the use of recycled materials in asphalt mixtures. This was based on experience from TxDOT engineers.

Identifying and Assessing Performance Test Appropriateness. The top three factors for TxDOT in selecting a performance test were: sample preparation, specimen conditioning and testing time, and repeatability.⁽¹⁷⁾ The duration needed for sample preparation, specimen conditioning and testing, and the need for more efficient quality control during production have been key considerations for TxDOT in the development of test criteria and the implementation of performance tests into the specifications. This is tied to the ability of testing aged specimens that are representative of a future critical pavement condition for cracking while keeping in mind the need for a quick turnaround time for test results. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications. Having qualified and trained technicians help to reduce the impact this factor might have on the overall implementation effort of performance tests.

Other important factors for TxDOT are field validation and material sensitivity. Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of TxDOT's motivations for implementation of performance tests. In the selection process, consideration was also given to the capability of the performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures (based on historical field performance of asphalt mixtures). The test results of local asphalt mixtures should not contradict known and observed field pavement performance.

Having TX test procedures available supported efficient implementation of performance tests for asphalt mixtures. TxDOT has used its own test method for HWTT (Tex-242-F) since the early 2000s, before the AASHTO T 324 test method was available, and the OT (Tex-248-F) since 2007.^(65,68)

TxDOT constantly revises and updates the test methods as deemed necessary based on new findings and through continuous communication and coordination with researchers, industry, vendors, etc. In the case of the OT, TxDOT invested in and supported the development of the OT equipment. In 2005, and as result of the TxDOT Project 0-4467, new OT equipment was manufactured and delivered to TxDOT's Materials and Tests Division (MTD) at the Cedar Park office in Austin, Texas.⁽⁶⁹⁾ The new upgraded equipment was made practical for incorporation into asphalt mix designs to complement the HWTT.

TxDOT is currently evaluating the feasibility of using the rapid rutting test (RRT), known as ideal shear rutting test (IDEAL-RT), at high temperature to evaluate the rutting performance of asphalt mixtures (ASTM WK71466).⁽⁴²⁾ The IDEAL-RT is being evaluated for potential use during production as a surrogate test for acceptance. TxDOT recognizes that simple performance tests for acceptance (surrogates) may require correlation/calibration with more fundamental/truth tests depending on observed distresses; for instance, the IDEAL-CT is correlated to the OT in the case of cracking and the IDEAL-RT is correlated to the HWTT in the case of rutting. Nonetheless, TxDOT recognizes that such correlations will likely to be project specific and on a mixture-by-mixture basis.

Surrogate tests for the HWTT and OT were evaluated for use during production.

Validating the Performance Tests. TxDOT's development of the initial performance test criteria is based on historical database of HWTT and OT results for an array of asphalt mixture types from various geographical regions of the State. Over the years, TxDOT supported and funded several research projects that analyzed and evaluated the HWTT and OT results in relation to field pavement performance. The asphalt mixture database of performance test results for plant-produced asphalt mixtures has been used to improve the test analysis methodologies and to update test criteria. Having a large database of test results for typical asphalt mixtures from TX along with their respective history of field pavement performance were key for TxDOT's implementation efforts of BMD. The following describes a few selected studies that were supported by TxDOT throughout the years.

Performance tests were validated through numerous studies.

- In the late 1990s, TxDOT evaluated the HWTT very extensively by investigating the effect of temperature and different antistripping agents on the results.⁽⁷⁰⁾ The tests were conducted on asphalt mixtures with aggregate from various sources throughout the State. The overall goal was to establish a reliable test method for TxDOT.
- In 2001, TxDOT initiated a 5-year study to determine a correlation between field pavement performance and HWTT results (TxDOT Project 0-4185).^(71,72) Different asphalt mixture types and aggregate sources were used in the study. Test sections were constructed to observe the performance of the asphalt mixture overlays under actual traffic and climatic conditions. Field pavement performance was monitored through visual pavement condition surveys and nondestructive tests for 4 years. Similar types of deformation patterns were assumed for both the laboratory specimens and field test sections (no stripping problems were observed in the field and laboratory specimens). At the end of this study, the HWTT results of the evaluated asphalt mixtures were correlated to their field pavement performance (an average ratio of 37 was found between the HWTT wheel pass and the equivalent single axle loads).
- In a recent study (TxDOT Project 5-6815), a database that contained more than 1,000 OT results collected over an 8-year period for 8 different asphalt mixtures typically used by TxDOT was examined and evaluated.^(73,74) The median, average, standard deviation, and COV for the CFE and CPR were computed from the three OT results for each asphalt mixture. The COVs for the OT number of cycles to failure were also calculated and documented for comparison purposes.

It should be noted that the preliminary acceptance limits for CFE and CPR were uniformly applied for all asphalt mixture types. However, different asphalt mixtures are used for different applications. Thus, it was decided that acceptance criteria should be established based on the function and role of each asphalt mixture type (i.e., tied to the critical strains and stresses that each layer is expected to experience during pavement design). Specification limits were selected based on a passing rate of 80 percent, thus assuming in general that 80 percent of current asphalt mix designs from TxDOT have exhibited acceptable pavement performance.

The newly established CFE and CPR limits for SP surface mixtures have been implemented in the SS 3074. The established limits for the remaining asphalt mixtures have been incorporated into revised specifications and are currently being reviewed and commented by industry.

Additional studies comparing performance test results to field performance from accelerated load facilities, field test section and test tracks include:

- TxDOT Project 0-6132 (2008–2012) evaluated the BMD approach in an APT study conducted in cooperation with LTRC at their ALF in Baton Rouge.⁽⁷⁵⁾ Performance data from this study confirmed the laboratory HWTT relationship to field rutting and the OT relationship to reflection cracking.
- TxDOT Project 0-6815 (2017–2020) compared the cracking performance of field pavement sections to their predicted performance from OT.^(73,74) The OT reasonably predicted the cracking performance of asphalt mixtures placed on different pavement test sections. The comparison between laboratory-produced asphalt mixtures and field cores from 17 field pavement sections revealed that asphalt mixtures that initially exhibited poor performance in the OT yielded worse OT results from the field cores extracted after around 4 years. The pavement sections were subjected to different truck volumes and included different types of asphalt mixtures (e.g., SMA-D, TOM), asphalt binder PG, and RAP content (0–23%). The cracking resistance of 10 asphalt mixtures used to build ten lanes at the FHWA ALF was also evaluated with the OT. A strong correlation was found between the OT results and the pavement performance data from the accelerated testing.
- In 2018, TxDOT sponsored two sections on the NCAT Test Track to compare the field performance of asphalt mixtures designed using SS 3074 to the Superpave volumetric approach under accelerated loading conditions (sections are loaded for 2 years). The NCAT Test Track results provided TxDOT with an additional robust validation of their BMD approach, thus providing TxDOT with initial confidence to move forward with low risk field projects.
- Further validation and refinements to the performance test criteria are anticipated with the 12 test projects that are being placed between 2019 and 2021 around the State (estimated to have 35 to 45 test sections). The robust effort is anticipated to result in a revised specification and related test methods for design and QA, and performance thresholds to provide a practical method to engineer each unique material combination.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. TxDOT MTD central laboratory is very well equipped to run and analyze all performance tests implemented or being evaluated for the BMD approach. This includes all necessary equipment for sample preparation, fabrication, and conditioning of asphalt mixture specimens. TxDOT MTD laboratories currently have 5 HWTT devices, 4 OT devices, and 1 IDEAL-CT test device. TxDOT is currently in the process of acquiring a sixth HWTT device. The HWTT devices are from two different manufacturers. Eight out of the 25 TxDOT district laboratories each own an HWTT device. While none of the district laboratories have an OT device, at least two districts have a plan to acquire an OT device. Some districts have converted/upgraded their existing press machines to be able to run IDEAL-CT. In general, funding and space resources for acquiring and installing new equipment in laboratories have not been a major issue for TxDOT. Contractors also started to invest in and acquire IDEAL-CT devices.

Managing Resources. The current TxDOT technician manpower and equipment capabilities have been acceptable. Maintaining an active MPL for laboratories approved to perform HWTT (Tex-242-F) helped TxDOT in maintaining an acceptable workload level (<http://ftp.dot.state.tx.us/pub/txdot-info/cmd/mpl/hamburgs.pdf>). The current MPL includes ~40 laboratories from consultants and contractors.

An active MPL exists for laboratories approved to perform the HWTT.

Evaluating Performance Testing. The OT was first introduced to control the cracking performance of asphalt mixtures during the design process in the laboratory as TxDOT districts started to use more of their recycled materials into their asphalt mixtures. Asphalt mixtures in TX were designed using the HWTT to improve their rutting potential that might have impacted their cracking resistance and flexibility. The TxDOT's adaption of higher high-temperature asphalt binder PG and the HWTT raised concerns that asphalt mixtures are drier and more susceptible to premature cracking.

The variability of the number of cycles to failure that is used as the OT performance index was a main concern for TxDOT in using the test for mix design verification and acceptance. Thus, in 2014 TxDOT initiated a study to investigate an alternative cracking methodology and improved testing specifications for the OT with less technical complications and uncertainties in the results. The study developed two new performance indices, the critical fracture energy (CFE) and the crack progression rate (CPR). The repeatability of the CFE and CPR were found to be better than the acceptable repeatability level defined as a COV of less than 20 percent. The new cracking methodology and performance indices (i.e., CFE and CPR) were later implemented in the SS 3074.

Conducting Inter-Laboratory Studies. TxDOT maintains an up-to-date MPL for all laboratories approved to perform HWTT (Tex-242-F). The approval process requires an initial split sample testing with the MTD central laboratory. Laboratories must also participate in the Annual State-wide Hamburg Wheel Tracking Test proficiency program. There is a plan for TxDOT to create a similar MPL for all laboratories approved to perform OT (Tex-248-F).

Historically, a COV of ~30 percent has been observed with the HWTT number of passes. Throughout the years, research studies were undertaken to study and improve the variability of the HWTT. The COV for the OT number of cycles to failure has been as high as ~40 percent. The refinement of the sample preparation procedure along with the implementation of a new OT cracking analysis methodology to calculate CFE and CPR resulted in a significant reduction in the variability of the test results (TxDOT Project 0-6815).^(73,74) Based on more than 1,000 OT test results from more than 380 different asphalt mix designs and 8 mixture types, the COV of the CFE and CPR ranged between 5–15 percent.

Under the current IAC, a round-robin study is planned among CTIS, CTR, TTI, and other laboratories to establish test results variability within each laboratory and between laboratories for the HWT, OT, and IDEAL-CT.

Task 5: Establishing Baseline Data.

Reviewing Historical Data & Information Management System. TxDOT has successfully used the HWTT in their mix design selection for several years, and the test has been included in their standard specifications since 2004. All HWTT results are properly stored in a database that is maintained by TxDOT. A similar database exists for OT results of asphalt mixtures from TX. The OT has been implemented in the standard specifications since 2014.

Analyzing Production Data. In general, contractors were supportive of the BMD approach. Continuous communication, dialogue, and partnering with industry helped in balancing both the agency and industry needs and concerns. Based on a contractor experience with test projects thus far, the following observations were made:

- Changes to asphalt mixtures to get acceptable performance testing values were material specific. In particular, the performance test results were found to be sensitive to the aggregate type and properties (e.g., specific gravities, absorptions, particle shapes). This required adjustments to bin percentages or the use of different aggregate sources. Aggregate suppliers' may be required to re-evaluate and adjust their aggregate production process.
- Aggregate breakdown in the plant-produced asphalt mixture can occur (depending on the aggregate source,) as demonstrated with an increase in the percent passing the No. 8 sieve. Adjustments in the aggregate bin percentages within the allowable production tolerances are needed to match the laboratory-produced asphalt mix design.
- An increase in binder content by 0.7–0.8 percent was observed in order to meet the OT criteria. Meeting the HWTT requirement was not an issue.
- The OT results were sensitive to conditioning and reheating of asphalt mixtures, thus resulting in out-of-specification acceptance test results. A standard protocol for conditioning and testing plant-produced asphalt mixtures is needed.
- The BMD allowed the use of up to 35 percent fractionated RAP when only up to 20 percent fractionated RAP was allowed in standard surface mixtures.
- A proper RAP stockpile management plan and process control are important for maximizing the use of RAP in an asphalt mixture. Fractionated RAP created flexibility in adjusting the composition of the RAP for the asphalt mix design and minimized the variability of the RAP material.
- Plant trial batching was a critical and important step of the process in order to make sure that the asphalt mixture will be in compliance during production. Plant-produced asphalt mixtures typically exhibited different performance test results than laboratory-produced asphalt mixtures during design.
- The help and support of the TxDOT MTD personnel with performance tests (training on equipment and test result calculations) was essential, especially at the beginning, in order to make sure that tests are being properly conducted in the contractor laboratory.
- No issues or challenges in meeting in-place density requirements were observed or encountered.

Plant trial batching was a critical step in mixture verification.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. The sensitivity of performance test results to asphalt mixture component properties or proportions (e.g., aggregates, asphalt binders, recycled materials, additives), volumetric parameters (e.g., air voids, VMA), and aging is an important factor for TxDOT. Contractors need to be able to make informed decisions on what changes can be made to the asphalt mixture composition and proportions in order to improve performance and meet applicable specification limits. TxDOT funded several research studies to evaluate the sensitivity of performance tests to material properties using asphalt mixtures typically used in Texas. This allowed TxDOT to build a large database of performance test results over the years, including the more than 200 aggregate sources throughout the State that can be used in asphalt mixtures. The database has been used to establish initial performance test criteria and continues to be used to refine and revise the performance test methods and their associated criteria. As an example, the following summarizes the findings from four select studies that evaluated the sensitivity of the performance tests to asphalt mix design variables.

A large database including aggregates from over 200 sources was used to examine trends in needed mixture adjustments.

- In 2005, TxDOT Project 0-4467 completed a study that evaluated the influence of modified asphalt binder (9 different asphalt binders) and aggregate (three different limestone aggregates) on reflection cracking resistance using the OT.⁽⁶⁹⁾ It was found that aggregate absorption has a substantial impact on the reflection cracking resistance of asphalt mixtures as demonstrated with the measured OT number of cycles to failure.
- In 2007, TxDOT Project 0-1707 evaluated the influence of aggregate type (e.g., gravel, igneous, limestone-dolomite), asphalt binder grade (e.g., PG 70-22, PG 76-22), asphalt mixture type, and additive (hydrated lime and liquid anti-strip) on HWTT results.⁽⁷⁶⁾ The HWTT parameters investigated included rutting, slope of the rutting curve, and the area beneath the rutting curve at specific cycles. Based on the results of the analysis, the additive type and PG of the asphalt binder were the two factors that mainly influenced the performance of the asphalt mixtures in the HWTT. This study also suggested that the influence of aggregate type on HWTT results can be related to the interaction between the aggregate and the asphalt binder in the mixture.
- In 2020, TxDOT Project 0-6923 evaluated the influence of asphalt binder type and source, and recycled material type and content on the HWTT, OT, and IDEAL-CT results.⁽⁷⁷⁾ The following summarizes the findings from this study:
 - The mechanical properties of asphalt mixtures were found to be very sensitive to the source of the asphalt binder, especially for modified asphalt binders. Asphalt mixtures using asphalt binders with the same PG can have considerable variation in their mechanical properties.
 - Changing the PG of the asphalt binder mainly influenced the stiffness and stability of an asphalt mixture. Thus, modifying the PG of the asphalt binder during the mix design process can help asphalt mixtures with poor rutting performance.
 - The inclusion of recycled materials, either RAP or RAS, must be limited to avoid crack-susceptible asphalt mixtures. The OBC of an asphalt mixture containing high contents of recycled material must be adjusted to minimize cracking.
- As part of TxDOT Project 0-6815 to improve the OT analysis methodology for cracking resistance of asphalt mixtures, the impacts of aggregate type and gradation, asphalt binder source and PG, binder content, recycled material content, and additives on the OT

parameters (CFE and CPR) were evaluated.^(73,74) The following summarizes the findings from this study:

- SP mixtures exhibited better cracking performance than DG HMA mixtures based on the CPR parameter. A definite trend was not observed for the CFE values between the comparable SP and DG HMA mixtures.
- The PG of the asphalt binders influenced significantly the CFE parameter but did not impact noticeably the CPR parameter.
- The CFE parameter did not show a definite trend when altering the aggregate gradation, but the CPR parameter changed systematically with the aggregate gradation. The CPR value increased as the aggregate gradation became finer (may be attributed to the reduction in the binder content due to the incorporation of finer aggregates into the asphalt mixture).
- Regardless of the aggregate gradation, the binder content significantly influenced the CPR parameter from the OT (an increase in binder content resulted in a decrease in CPR). A definite trend was not observed for the CFE parameter.
- The source of an asphalt binder influenced both CFE and CPR parameters.
- The asphalt binder source influenced the CFE parameter of TOM mixtures significantly and the CPR parameter marginally.

The sensitivity of performance tests to material properties will continue to be evaluated with the asphalt mixtures sampled from the 2019–2021 test projects and other future projects. TxDOT will continue to populate performance test results into its database, which will help in refining specifications and guidelines to design asphalt mixtures with satisfactory cracking resistance. The buildup of the database with the new OT parameters/ performance indices (i.e., CFE and CPR) is being conducted while maintaining a continuous communication and discussion with the industry.

Task 6: Specifications and Program Development.

Developing Pilot Specifications and Policies. TxDOT has successfully used the HWTT in their mix design selection for several years, as the test has been included in their standard specifications since 2004. TxDOT has also had success using performance tests with their specialty asphalt mixtures, which now accounts for approximately 20 percent of their total asphalt mixtures. Performance testing has been part of TxDOT projects. TxDOT is now developing the BMD approach for selecting the OBC for all of TxDOT’s asphalt mixtures based on the HWTT and OT results.

The HWTT has been used as a standard since 2004. Specialty mixtures (about 20 percent of the program) have used the HWTT and OT. BMD is now being developed for dense-graded mixtures.

TxDOT has implemented SS 3074 for Superpave Mixtures – Balanced Mix Design that allows for 30 percent of maximum ratio of recycled asphalt binder to total binder. Most of the current effort has focused on applying performance testing to the design and acceptance of SP surface mixtures. Monotonic load-based tests including IDEAL-CT and IDEAL-RT are being evaluated

Surrogate tests for rutting and cracking are being evaluated.

for possible use as surrogate performance tests during production after being correlated to OT and HWT, respectively.

Several test projects will be selected from participating TxDOT districts to validate the testing requirements and design specifications for BMD. The test projects are anticipated to spread throughout the entire State. Each test project site comprises multiple test sections including a control test section. The test sections will be comprehensively investigated and monitored. Two test projects have been constructed thus far and four new test projects are scheduled to be constructed in July–September 2020. The remaining test projects are planned for summer of 2021. The factors that are being considered in the various test projects are: RAP, RAS, soft virgin asphalt binder, RA, warm mix asphalt produced at low temperature, N_{design} , gradation, and aggregate quality. It should be noted that some test sections will include RAP at different ratios of recycled asphalt binder to total binder.

The overall process for selecting and completing test projects involves significant and continuous coordination efforts among the various stakeholders. First, an invitation email is sent out to all TxDOT districts exploring their interest in participating in the test projects. For interested districts, follow-up conversations are undertaken to go over the project goals, benefits, and expectations. Next, district interest in the type of asphalt mixtures is identified and candidate test projects are solicited. Discussions are also carried out with involved contractors on the asphalt mix design requirements and the potential changes to accommodate the increased use of RAP while considering their specific challenges and issues. Once the test project is selected and confirmed, additional coordination meetings are held between TxDOT district and MTD personnel, contractor, additives suppliers, and at least one representative from the universities’ team to discuss the overall progress and planning activities including specifications, mix designs, test sections layout, pre-construction evaluation, construction schedule, sampling plan, etc. This may take up to seven 20–30 minutes coordination meetings.

So, industry partners volunteer for test projects, which accelerates the learning curve and practicality of the approach.

CTIS, CTR, and TTI will provide support to TxDOT and contractors in all three phases of pre-construction, asphalt mix design and placement, and post-construction. This includes visual distress survey and layout of test sections, asphalt binder and blend characterization, asphalt mix design support, trial batch validation, asphalt mix design performance correlations, asphalt mix design verification, production sample testing, and post-construction field core samples testing.

According to the current SS 3074 for Superpave Mixtures – Balanced Mix Design, performance testing during production is to be conducted at the frequencies shown in table 35. All performance testing is to be performed by TxDOT MTD or a designated laboratory from the MPL.

Table 35. Minimum Production Testing Frequency According to TxDOT.

Entity	Gradation	Volumetrics ² and In-place Air voids	Binder Content	HWTT	OT	IDEAL-CT Test
Contractor	1 per subplot	–	1 per subplot	–	–	–
TxDOT	1 per 12 sublots ¹	1 per subplot ¹	1 per lot ¹	1 per project ³	1 per project ³	1 per project ³

–Not applicable.

¹1 per day if 100 tons or more are produced. No testing is required when less than 100 tons are produced.

²Laboratory-molded density and bulk specific gravity, VMA, and Gmm.

³Testing performed by MTD or designated laboratory.

TxDOT may perform an HWTT or OT at any time during production. In case of failing results, production is suspended until further HWTT or OT production samples meet the specified values in table 33. In addition to testing production samples, TxDOT may obtain cores and perform HWTT on any areas of the roadway where rutting is observed. Production is also suspended until further HWTT meet the specified values when the core samples fail the HWTT criteria in table 33. TxDOT may require up to the entire subplot of any mixture failing the HWTT to be removed and replaced at the contractor's expense.

If TxDOT's HWTT results in a remove and replace condition, the contractor may request that TxDOT confirm the results by re-testing the failing material. The MTD will perform the HWTT or OT and determine the final disposition of the material in question based on the test results.

The IDEAL-CT correlation with OT that was developed during the project trial batch will be used to monitor cracking performance during production. If at any time the minimum correlation limit is not met, the OT is then used to determine the compliance of the produced asphalt mixture with the performance specifications shown in table 33.

Conducting Pilot Projects. For implementation of BMD on Superpave dense-graded mixtures, about 20 projects will be piloted based on volunteers from the districts and contractors from 2019 to 2021. Industry partners volunteer for test projects which accelerates the learning curve and practicality of the approach.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. The Tex-242-F Hamburg Wheel-Tracking Test is covered under the Hot Mix Asphalt Center (HMAC) certification program managed and operated by TXAPA.⁽⁷⁸⁾ Several training videos are provided by HMAC including two of them that are specifically made for Tex-242-F (<https://www.youtube.com/c/HMACVideos/videos>). Laboratories must also participate in the Annual State-wide HWTT proficiency program.

Performance tests are part of the standard certification program. Laboratories with HWTT must participate in an annual proficiency program.

Currently none of the other performance tests (i.e., OT, IDEAL-CT, and IDEAL-RT) are included in the HMAC certification program. TxDOT envisions that these performance tests will be part of the certification program. In the interim, TxDOT will continue to support and require the on-going in-house certification program on performance testing for State technicians.

TxDOT plans on having training activities related to BMD, including workshops for laboratory testing and asphalt mix design and adjustments.

Task 8: Initial Implementation.

TxDOT has successfully used the HWTT in their mix design selection for several years, as the test has been included in their standard specifications since 2004. TxDOT has also had success using performance tests with their specialty asphalt mixtures, which now accounts for approximately 20 percent of their total asphalt mixtures. Performance testing has been part of TxDOT projects. TxDOT is now developing the BMD approach for selecting the OBC for all of TxDOT's asphalt mixtures based on the HWTT and OT results. TxDOT is doing this on a voluntary basis with a goal of have test sections on about 20 projects from 2019 to 2021.

BMD was implemented on pilot projects on a voluntary basis. The goal was to have 20 projects over two years.

OBSERVED BENEFITS

The use of BMD on test field projects allowed contractors to utilize innovative and recycled materials (e.g., RAP, warm mix additives, RAs) in order to produce asphalt mixtures that are in compliance with TxDOT specifications. Furthermore, the traditional volumetric-based mix design did not provide optimum performance for asphalt mixtures with higher RAP content. Performance testing helped in designing asphalt mixtures with higher RAP contents; thus, allowing for the production of economical and environmentally friendly asphalt mixtures without jeopardizing performance.

Cost savings from increasing RAP use was a motivation to implement BMD.

The asphalt mixtures designed using the BMD approach were in general easier to compact in the field and to reach target in-place density, mainly due to the increase in the binder content. TxDOT Project 0-6132 determined that using the BMD approach in one of the districts resulted in a savings of over \$5 per ton of asphalt mixture by moving to a less expensive asphalt binder while improving the mixture's overall engineering properties.⁽⁷⁵⁾ No issues were encountered with construction of any of the sections with excellent field performance reported at the time of the study.

TxDOT had about 16 million tons of asphalt mixture placed in last fiscal year. Thus, if every ton of asphalt mixture produced contained 15 to 20 percent RAP, TxDOT would have consumed 2.4 to 3.2 million tons of RAP. For a \$5 per ton saving for using 15 to 20 percent RAP, the total annual savings for TxDOT would be about \$80 million. Accordingly, TxDOT believes that the implementation of BMD should result in cost savings by providing contractors with more flexibility during the asphalt mix design and allowing more opportunities to use recycled materials without jeopardizing asphalt pavement performance.

FUTURE DIRECTION

TxDOT has been successfully using the BMD approach for specialty asphalt mixtures and envisions using it on all of its standard asphalt mixtures using a stepwise approach (phased-in implementation). The BMD is primarily founded on the HWTT and OT, with which TxDOT has had a long history of use. The implementation of the BMD for acceptance required the use of surrogate tests that are simple and quick to run. This necessitated the development of a correlation between the surrogate tests (i.e., IDEAL-CT and IDEAL-RT) and what is considered

to be the truth tests (i.e., OT and HWTT). A series of studies and activities are needed in order to ensure full implementation of BMD for design and acceptance. Some examples are provided below:

- Continue the effort with the test projects to cover the different materials throughout the State.
- Continue monitoring the field pavement performance and use information to validate and modify as needed the BMD approach and the established performance test criteria.
- Verify and validate the correlation between the OT and IDEAL-CT. Establish a similar correlation between the HWTT and IDEAL-RT.
- Optimize the laboratory aging conditions for asphalt mixtures to better simulate field behavior. The aging methods are anticipated to be used when the rutting and cracking resistance of asphalt mixtures are being evaluated as a part of the BMD process.
- Establish necessary precision and bias statements for utilized performance tests.
- Document the cost-benefit of the BMD specifications in comparison with other mix design specifications such as SP mixtures, DG HMA, and SMA mixtures.

The full implementation effort needs to be supplemented with proper communication, training, and education activities. Contractors will need to be educated on what changes can be made to the asphalt mixture composition or proportions in order to make informed and cost-effective decisions to improve performance and meet applicable specification limits.

CHAPTER 8 VIRTUAL SITE VISIT: VDOT (MAY 2020)

INTRODUCTION

In mid to late 1990s, VDOT adopted the Superpave method to identify the optimal aggregate blend and its corresponding OBC.⁽⁷⁹⁾ This included the implementation of the Superpave PG asphalt binder system. Accordingly, VDOT reduced the allowable reclaimed asphalt pavement (RAP) percentages as the asphalt binder suppliers switched over to the new PG system. This stemmed from the fact that no guidance for the use of RAP in asphalt mixtures was originally provided by the Superpave design method, and because the effects of aged reclaimed asphalt binders on the PG of virgin asphalt binders were not known. Thus, VDOT adjusted its requirements to specify no more than 20 percent RAP (down from 50 percent RAP) in surface and intermediate asphalt mixtures (designated as SM and IM, respectively).

The implementation of Superpave resulted in dense-graded asphalt mixtures that had coarser aggregate blend gradations and low binder contents that did not perform well (durability and cracking issues). Thus, VDOT made adjustments to their Superpave criteria to replicate the finer and higher binder content mixtures that were produced prior to adopting Superpave. Nonetheless, VDOT continued to allow up to a maximum of 20 percent RAP in asphalt mixtures.

This RAP limit stayed in place for VDOT surface asphalt mixtures until 2007, when VDOT explored the possibility of increasing RAP content to 30 and 35 percent without the requirement to use softer virgin asphalt binders (i.e., PG bump down) not common in the Virginia market. Since 2009, changes were implemented to VDOT specifications to allow up to 30 percent RAP in SM and IM with PG change, and up to 35 percent RAP in base asphalt mixtures (BM) with softer PG.

Late fall of 2017, Benchmarking of Asphalt Mixtures for Support of Higher-RAP Pilot Projects (VDOT UPC #112606) was initiated as a response to the VDOT Chief Engineer's charge to develop specifications for using surface asphalt mixtures with higher RAP contents (more than the 30 percent allowed per standard specification) during the 2018-2019 paving season.⁽⁸⁰⁾ This effort followed field trial projects in 2013-2014 with 40-45 percent RAP content and continuous discussions with industry about high RAP content pilot projects. Note that as of 2016, VDOT requires that all dense-graded asphalt mixtures (SM, IM, and BM) be designed at 50 gyrations.

The “why” for implementation of BMD was to increase durability, while allowing for increased contractor innovation.

Since cracking is a main concern with asphalt mixtures in Virginia, including high RAP asphalt mixtures, the Benchmarking study evaluated several cracking tests in order to determine which available test provided rational results and would be implementable. As a result, the Benchmarking study recommended the use of Cantabro (AASHTO TP 108), APA (AASHTO T 340), and IDT Cracking Test (formerly known as IDEAL-CT) for cracking resistance (ASTM D8225) in both the regular dense-graded and the high RAP asphalt mix design specifications.^(16,50,81) This also included recommendations for initial performance test criteria.

BMD APPROACH

VDOT developed in 2020 two special provisions for BMD of surface asphalt mixtures:

- Special Provision for Balanced Mix Design (BMD) Surface Mixtures Designed Using Performance Criteria: RAP percentage is not addressed in this specification; the standard specification governs (a maximum of 30 percent RAP).⁽⁸²⁾
- Special Provision for High Reclaimed Asphalt Pavement (RAP) Content Surface Mixtures Designed Using Performance Criteria: This specification defined “high RAP” as a minimum of 40 percent, but no maximum was specified.⁽⁸³⁾

Figure 17 shows a flowchart of the overall BMD for the two special provisions in 2020 for surface mixtures. The flowchart highlights the major steps for undertaking an asphalt mix design according to VDOT specifications. The requirements for volumetric design, gyratory compaction efforts, and performance testing are summarized in table 36 and table 37.

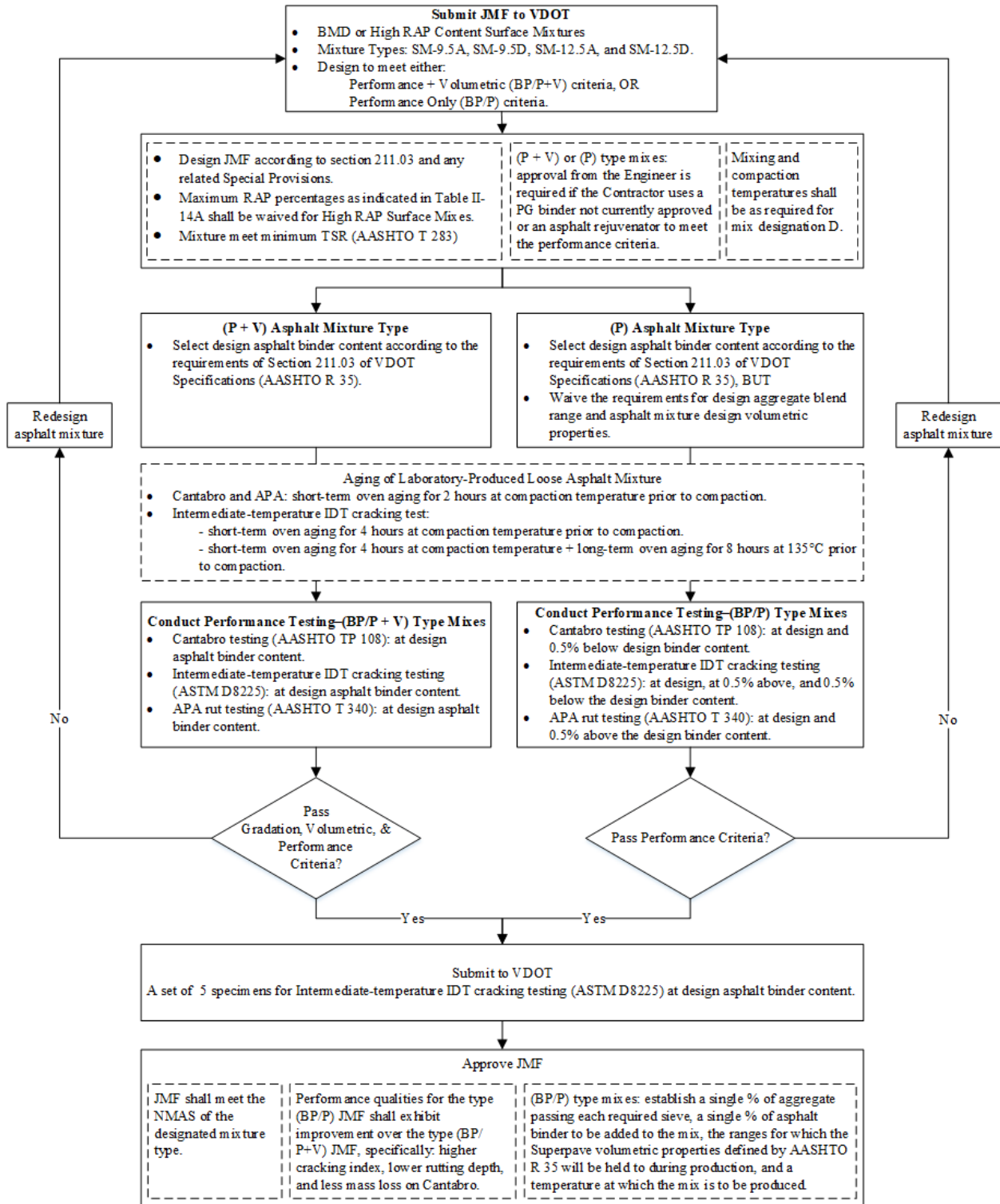
BMD pilot projects were optional. Contractors could select Approach A (performance + volumetrics) or Approach D (performance only).

The VDOT’s BMD for designing asphalt mixtures and approving JMFs allows for using Approach A *Volumetric Design with Performance Verification* that is referred to by performance + volumetric (BP/P + V), and/or Approach D *Performance Design* that is referred to by performance (BP/P).

In approach A (i.e., VDOT BP/P + V), the asphalt mixture has first to pass all gradation and volumetric property requirements before being evaluated in the designated performance tests. Subsequently, the asphalt mixture at the design binder content needs to pass the performance criteria for durability, cracking, and rutting. If the asphalt mixture fails any of the criteria, the contractor has to redesign and resubmit the asphalt mixture for JMF approval following the same process.

In approach D (i.e., VDOT BP/P), the design aggregate blend range and volumetric property requirements are waived; however, NMAAS requirements are still in place. The asphalt mixture at the design binder content needs to pass the performance criteria for durability, cracking, and rutting. Performance testing results have to be reported at design binder content along with those at 0.5 percent above and/or below the design binder content.

In the case of BMD surface asphalt mixtures, i.e., (BP + V) or (BP) type mixes, a PG of the asphalt binder is recommended depending on RAP content (table 38). On the other hand, a PG is not specified for the high RAP surface asphalt mixtures; it is determined by the asphalt mix design and performance testing. However, approval from VDOT is required if the contractor uses an asphalt binder that is not currently approved or a RA to meet the performance test criteria.



Note: TSR is part of asphalt mix design approval during production.

Figure 17. Chart. Overview of VDOT's BMD approach in 2020 for BMD and high RAP content surface mixtures.

Table 36. VDOT Specifications for Volumetric Design Requirements and Gyrotory Compaction Effort for (P+V) Type Surface Mix.

Mixture Type	Required Density (% of Theoretical Max. Specific Gravity)	VMA (Minimum %)					VFA (%)	Dust-to-Binder Ratio	N _{des}
		N _{design}							
	NMAS (mm)								
		25	19	12.5	9.5	4.75			
SM-9.5A	96.0	–	–	–	16.0	–	75–80	0.7–1.3	50
SM-9.5D	96.0	–	–	–	16.0	–	75–80	0.7–1.3	50
SM-12.5A	96.0	–	–	15.0	–	–	73–79	0.7–1.3	50
SM-12.5D	96.0	–	–	15.0	–	–	73–79	0.7–1.3	50

–Not applicable.

Table 37. VDOT Specifications for Mix Design Performance Testing Requirements for (P+V) and (P) Type Surface Mixtures.

Index Parameter	Test	Criteria
Cantabro mass loss	AASHTO TP 108	≤ 7.5%
Cracking tolerance index	ASTM D8225	≥ 70 at 25°C
APA rut depth	AASHTO T 340	≤ 8.0 mm after 8,000 passes at 64°C
TSR	AASHTO T 283	≥ 0.80 at 25°C

Table 38. VDOT Recommended PG of Asphalt Binder for (BP+V) and (BP) Type Surface Mixtures.

Mixture Type	% RAP ≤ 25.0%	25% < % RAP ≤ 30%
SM-9.5A, SM-12.5A	PG 64S-22	PG 64S-22
SM-9.5D, SM-12.5D	PG 64H-22	PG 64S-22

An antistripping additive is required in all asphalt mixtures (hydrated lime, an approved chemical additive, or a combination of both). Hydrated lime is to be added at a rate of minimum 1 percent by weight of the total dry aggregate. The chemical additive is to be added at a rate of minimum 0.30 percent by weight of the total binder content of the mixture. The contractor submits with the asphalt mix design the TSR (AASHTO T 283) that has to meet a minimum of 0.80.⁽¹³⁾ The asphalt mixture is conditioned according to AASHTO R 30 before being compacted.⁽⁴⁴⁾ VDOT checks TSR requirement for the first 500 tons of production on plant-produced asphalt mixtures.

In comparison to AASHTO M 323 and AASHTO R 35, due to ongoing concerns about mixture durability, in 2016 VDOT implemented the following key modifications to their volumetric design criteria (table 36):

- Specified 50 gyrations for design and acceptance of BMD or high RAP surface mixtures.
- Increased the VMA requirement by 1 percent for both NMAS of 9.5 and 12.5 mm.
- In general, increased the lower and upper limits of voids filled with asphalt (VFA).
- Increased the lower and upper limit of the dust-to-binder ratio by 0.1.

The above changes to AASHTO M 323 and AASHTO R 35 are aimed at increasing the durability and cracking resistance of an asphalt mixture by letting more asphalt binder into the mixture without jeopardizing its resistance to rutting (the higher the VMA, the higher the binder

content for a given air void level). Similar changes were introduced for intermediate course mixtures and base course mixtures in 2019. The interest in BMD has been a continuation of efforts to improve asphalt mixture durability.

The high RAP surface mix specification was unique for the following two reasons:

- The specification called for a minimum (not a maximum) of 40 percent RAP to be added to the asphalt mixture. The minimum RAP content was specified to differentiate from the traditional asphalt mixtures with maximum 30% RAP.
- The specification did not prescribe a specific PG of the asphalt binder. Any PG was allowed provided that the asphalt mixture met all of the required volumetric property and/or performance testing requirements.

IMPLEMENTATION PROCESS OF BMD

Task 1: Motivations and Benefits of BMD.

The motivation for implementation of BMD in Virginia was primarily that the Superpave asphalt mixtures (even after improvements were made for durability and performance) did not perform as well as had been expected. Durability and cracking were a main concern with Superpave.

Superpave asphalt mixtures did not perform as expected even after improvements were made.

With RAP, cracking was even more of an issue, and given the requests from the industry to use higher quantities of RAP, it seemed prudent to develop a mix design method that would allow for contractor innovation.

Task 2: Overall Planning.

Identification of Champions. As the research group, VTRC took the lead in the applied research necessary to develop the framework for implementation on VDOT projects. However, VDOT’s Materials Division was very involved as they were responsible for project application, and the Assistant State Materials Engineer was the “champion” for the initiative.

Establishing a Stakeholders Partnership. Collaboration and cooperation between VDOT Materials Division, VTRC, VDOT District Staff, industry, and academia is important for a successful and smooth implementation of performance tests as part of asphalt mix design and acceptance. This involves good communication and continuous dialogue with the industry, knowledge transfer, and necessary education and training.

Internally, having a strong and established research council is supporting the development effort of BMD. Externally, having trusted industry partners that volunteered for pilot projects accelerated the learning curve and practicality of the approach. Communicating with contractors the impact of new specifications on the design and acceptance of their asphalt mixtures was key to facilitating implementation.

To support a smooth implementation of performance tests as part of asphalt mix design and acceptance, VDOT established a “BMD Advisory Committee” and a “BMD Technical Subcommittee” to assure proper

Two stakeholder groups were formed. The BMD Advisory Committee handled executive-level decision. The BMD Technical Subcommittee handled technical decisions.

communication and continuous dialogue with stakeholders and to provide timely and constructive technical inputs. The “BMD Advisory Committee” provides periodic status updates for the BMD initiative for key executive stakeholders; and a periodic forum for dialogue about progress and key milestones as the effort progresses. The “BMD Technical Subcommittee” oversees the progress of related research projects, provide technical inputs, and support the development of the BMD special provisions and guidance.

Establishing Goals. It should be noted that VDOT maintains a total of 128,770 lane miles in interstate, primary, and secondary systems; it is anticipated that initially the majority of BMD mixes will be placed on non-interstate systems, as BMD is currently limited to standard dense-graded mixes, and interstates in Virginia are most commonly paved with polymer-modified mixes and/or SMA.

The implementation is in the early stages. VDOT currently has general guidelines for project selection of BMD in which the project includes at least 4,000 tons of placed asphalt mixture. These will be further developed in the future. In 2019, two projects were completed by two separate contractors. In 2020, it is anticipated that at least four field trial projects will be completed under the study Balanced Mix Design for Asphalt Mixtures: High RAP Field Trials (VDOT UPC #115763).

Mapping the Tasks. A simplistic summary of VDOT’s overall method for the implementation of performance tests comprised the following steps: 1) select the BMD approach; 2) evaluate many performance tests and then make a selection; 3) refine the test procedures and equipment with ILS; 4) develop initial performance tests criteria and related specifications; 5) validate performance tests’ criteria through field trials; and 6) select quality criteria for acceptance.

Mapping was done with simple, “big-picture” tasks.

Identifying Available External Technical Information and Support. There is an HVS experiment that is currently ongoing at Virginia Tech Transportation Institute (VTTI). The HVS experiment involves six different asphalt mixtures designed using the VDOT BP approach in accordance with the special provision for BMD surface mixtures using performance criteria.

Developing an Implementation Timeline. VDOT created an overall timeline for a statewide implementation of BMD (figure 18). It includes development of performance test criteria for cracking and rutting, construction and evaluation of pilot projects, VDOT acquisition of laboratory equipment, development and execution of training materials, as well as refinement of specification requirements as suggested by the pilot projects. VDOT identified the need to create more detailed work processes for each of these steps at the appropriate time.

BMD implementation was guided by a timeline.

VDOT/VTRC acknowledges that the current timeline schedule is aggressive, and the statewide implementation might be phased in based on available resources (e.g., equipment, laboratory space, and staff). Additionally, VDOT/VTRC has not yet defined how “implementation” will ultimately be defined (i.e.: BMD for all mixtures/ routes/traffic levels, or only a portion; performance testing for design only, or also for production and acceptance; or some other definition. Staff are mindful that the definition of implementation will significantly affect the extent to which the timeline can be aggressive.

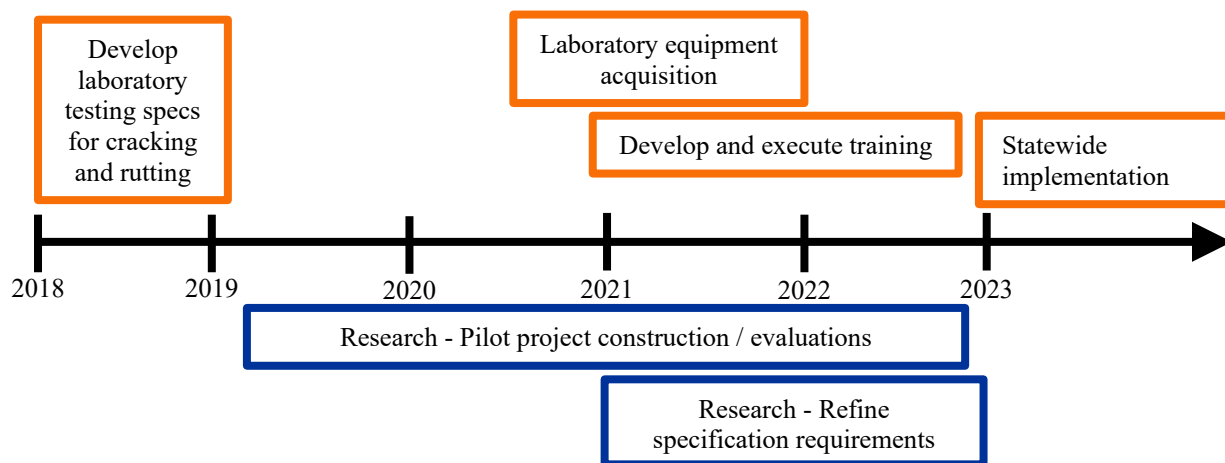


Figure 18. Chart. VDOT timeline in 2020 for statewide implementation of BMD.

Task 3: Selecting Performance Tests.

Identifying Primary Modes of Distress. The implementation of Superpave resulted in dense-graded asphalt mixtures that had coarser aggregate blend gradations and low binder contents that did not perform well (durability and cracking issues). Cracking is a main concern with high RAP asphalt mixtures.

Cracking from mixtures with low binder contents and high RAP contents needed addressing.

Identifying and Assessing Performance Test Appropriateness. The selection of performance test must be matched to the mode of distress of pavement in-service, otherwise it negates the purpose of relating the BMD to ultimate in-service pavement performance. The following 6 tests were initially considered and evaluated as part of the Benchmarking study for possible use in the BMD. The original reason for the selection of each performance test is also included.⁽⁸⁴⁾

Multiple performance tests were evaluated through a formal benchmarking research study.

- Cantabro test for durability, AASHTO TP 108: test was selected due to the limited number of durability tests available and for its simplicity.
- APA test for rutting, VTM-110: test was selected for initial testing due to its frequency of use and familiarity in Virginia as a rutting test. The test method recommendation was updated to follow AASHTO T-340 for consistency with current practice.⁽⁸⁵⁾
- OT for resistance to general and reflective cracking, Tex-248-F: reflection cracking distress is commonly observed throughout Virginia, particularly in asphalt overlaying jointed PCC pavement. This test has also been successfully implemented in other BMD specifications, e.g., New Jersey DOT and Texas DOT.
- I-FIT for cracking resistance, AASHTO TP 124: test was selected based on the promise it has shown in research work conducted at VTRC and elsewhere (e.g., Illinois DOT).
- N_{flex} factor for cracking resistance, Draft AASHTO standard method: This test consists of loading specimen in indirect tensile mode using a Marshall press or similar load frame. This test was selected based on promise shown elsewhere and the ability for VDOT and/or contractor to use a gyratory specimen (N_{design}) already produced for quality control and assurance purposes.^(86,87)

- IDT Cracking test (formerly known as IDEAL-CT) for cracking resistance, ASTM D8225: test was selected based on simplicity (no cutting is required and many contractors already possess the necessary load frames), speed of testing, minimal cost of equipment, and promise shown by other research groups.

Extensive laboratory evaluations of these tests were conducted as part of the initial effort. As a result of the Benchmarking study, the Cantabro, APA, and IDT Cracking tests were selected for further investigation and were included in the two special provisions for BMD and High RAP content surface mixtures.

The top four factors for VDOT in selecting a performance test are: sample preparation, specimen conditioning and testing time, repeatability, and training needs.⁽¹⁷⁾ VDOT has noted that the ability of the test to relate to in-service performance is inherent to their entire approach, but final selection was driven by the potential to implement the test. The duration needed for sample preparation, specimen conditioning and testing, and the need for more efficient quality control during production have been key considerations for VDOT in the development of test criteria and the implementation of any performance test into the specifications. This is tied to the availability and cost of equipment needed to prepare, fabricate, and test specimens. Having an acceptable repeatability (within laboratories) and reproducibility (between laboratories) of test results is key for successful implementation of specifications. Having qualified and trained technicians helps to reduce the impact this factor might have on the overall implementation effort of performance tests.

Other important factors for VDOT are field validation and material sensitivity. Field validation and correlation of performance test results with measured field performance data is the basis for any BMD approach and was one of VDOT's motivations for implementation of performance tests. In the selection process, consideration was also given to the capability of a performance test to provide consistent results that follow common sense trends and rankings of the tested asphalt mixtures. The test results of local asphalt mixtures should not contradict known and observed field pavement performance, or recognized correlations between the mode of distress under evaluation and volumetric properties.

The feasibility of using monotonic loading-based tests to evaluate the rutting performance of asphalt surface mixtures is being researched by VTRC as surrogate performance tests for the APA during production. These tests include but are not limited to high-temperature IDT strength, ideal shear rutting (IDEAL-RT), and Marshall Stability. In general, these tests are quick procedures that use currently available equipment in the laboratory with slight modifications as needed; thus, requiring minimal investments from both VDOT and the industry, and therefore allowing for more tests to be completed within normal working hours. The implementation of such tests reduce the overall need for VDOT manpower and accelerates the time to test and report back the results of sampled asphalt mixtures during production to the contractor (quick turnaround time).

Validating the Performance Tests. VDOT development of the initial specification has been based on benchmarking typical asphalt mixtures currently in use within Virginia. Plant-produced asphalt mixtures from 11 field projects were collected from various geographical regions of the State and tested (reheated samples) in VTRC laboratories. VDOT's approach for the

development of test criteria is based on testing of asphalt mixtures with known history of field performance to correlate to laboratory test results. However, such performance history was not available for the 2015 typical asphalt mixtures used in the Benchmarking study. This was due to major specification changes in 2015 that comprised a reduction from 65 to 50 gyrations and an additional limitation on the No. 30 sieve for 9.5mm and 12.5mm NMAS dense-graded surface asphalt mixtures. Nonetheless, the established database of test results for the 2015 benchmarked asphalt mixtures is still being used in the BMD development efforts for comparison with field pavement performance as such data become available.

Three methods were considered to establish initial performance test criteria using the benchmarked asphalt mixtures:⁽⁸⁴⁾

- Method 1 (conservative application): Set the threshold at a value that will allow all tested asphalt mixtures to pass the criteria (i.e., a maximum value above or equal to the highest observed rutting or mass loss value; a minimum value below or equal to the lowest cracking index). This assumes that all mixtures tested will perform satisfactorily in the field as they meet the prescribed volumetric requirements.
- Method 2 (average): Use the average value of all tested mixtures for each of the performance tests.
- Method 3 (average \pm standard deviation): Set the threshold at the average value plus (rutting and mass loss value) or minus (cracking index) the average standard deviation of all tested asphalt mixtures to incorporate mixture and test variability.

The analysis and scrutiny of performance test results led to the selection of:⁽⁸⁴⁾

- A maximum 7.5 percent for Cantabro loss based on Method 1: there was no evidence of durability concerns among the tested asphalt mixtures.
- A maximum 8 mm for APA rut depth based on Method 1: there was no evidence of rutting concerns among the tested asphalt mixtures.
- A minimum 70 for cracking tolerance index based on Method 2: even though none of the evaluated asphalt mixtures was shown to be particularly susceptible to cracking at the time of testing after 2 years in service, the cracking criteria was selected aggressively such that an emphasis was placed on cracking resistance in the BMD specification. Cracking was thought to be the biggest area of concern, especially for high RAP asphalt mixtures.

The plan for validating performance test criteria comprises sampling and testing of additional asphalt mixtures. This is currently being conducted by VTRC as part of the PMD–Phase I study that was initiated in 2018. Asphalt surface mixtures were sampled and tested to expand the database of test results for typical dense-graded asphalt surface mixtures.⁽⁸⁸⁾ The study also included marginally performing asphalt mixtures that can be used to evaluate the sensitivity of the performance test methods and criteria. A total of 13 asphalt mixtures were collected and comprised the following specimen types:

- 6 field projects: testing performed on plant-compacted, reheated loose mixture, and field core specimens.
- 7 projects with plant sampling only: testing performed on plant-compacted and reheated loose mixture.

The additional test results are anticipated to provide a more robust data sample for the determination and validation of appropriate performance test criteria. In the case of field projects, the actual in-service pavement performance of the tested asphalt mixtures is being monitored throughout their lives to provide information necessary to validate the initial performance test criteria.

Moreover, additional criteria may be established specifically for high RAP asphalt mixtures with RAs. Work is also ongoing to select an IDT-based surrogate test and develop the associated preliminary test criteria to evaluate and accept asphalt mixtures designed following the BMD approach.

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating.

Acquiring Equipment. While VTRC is very well equipped to run and analyze all performance tests recommended or being evaluated for the BMD approach, VDOT laboratories have currently none or, at best, limited performance testing equipment. VDOT has been investing in new equipment and accessories in order to be able to undertake performance testing, especially since some of the old press machines that are in existence fail to meet the IDT Cracking test requirements. The challenge is to be able to find the resources to acquire equipment. Currently, VDOT has procured equipment for State laboratories including Cantabro, IDT Cracking, and APA through funding from VTRC; IDT Cracking equipment had already been purchased for each district laboratory at the time of the site visit in 2020. Two APA devices have been acquired; one each for the Central Laboratory and the Salem District laboratory. This effort involves additional resources to create new areas in the laboratories to accommodate equipment.

Findings from the PMD–Phase I study revealed the potential need for stricter specifications for equipment for it to be used in a BMD approach. There is a need for a study to assess and develop equipment specifications.

Contractors are also investing in certain equipment and associated training efforts. Having simple and practical performance tests (e.g., IDT Cracking), made it easier and faster for contractors to setup their laboratories for testing.

Managing Resources. Additional resources and laboratory spaces are also needed for sample preparation equipment (e.g., conditioning chambers, water baths, and aging ovens). Based on the current technician manpower and equipment capabilities, State laboratories will only be able to handle a limited number of BMD projects. The transition to the new performance tests will need to be accomplished while continuing to meet the needs for the regular workload with current manpower.

Staffing and laboratory space are being evaluated to determine the number of BMD projects.

Evaluating Performance Testing. Having existing standard test methods available supported efficient implementation of performance tests for asphalt mixtures within VDOT. AASHTO or ASTM standard test methods are available for Cantabro, APA, and IDT Cracking tests, and VDOT incorporated the methods for Cantabro and IDT cracking into the BMD approach. However, VDOT has used its own test method for APA (VTM-110) since the early 2000s,

before the AASHTO T340 test method was available. VTM-110 differs from AASHTO T340 as it specifies a target air void level of 8 percent for compacted specimens (compared to 7 percent in AASHTO T 340), a hose pressure of 120 psi (compared to 100 psi in AASHTO T 340), a wheel load of 120 lb (compared to 100 lb in AASHTO T 340), and a standard test temperature of 49°C.

Instead of continuing the use of VTM-110 for the APA test, during initial work for VDOT's BMD effort, AASHTO T 340 was used to establish a performance test criterion for APA rut depth in order to bring VDOT practice into agreement with national methods. AASHTO T-340 requires the use of 7 percent air voids for compacted specimens, 100 psi hose pressure, and 100 lb wheel load. In addition, the test temperature as part of the BMD effort was set to 64°C. This created discrepancies between the collected data and the existing database of past APA test results. Nonetheless, this was thought to be acceptable since the VDOT BMD effort started around the same time when major changes in specifications were implemented on all VDOT dense-graded asphalt mixtures. The change in specifications necessitates the monitoring of field pavement performance of asphalt mixtures designed according to latest specifications for another 3-4 years before fully validating the initially established APA rut depth criterion. The historical database of APA test results can still be used after correlating the results obtained from the two standard test methods (i.e., AASHTO T 340 and VTM-110), which can be done by comparing test results from both test methods for the same asphalt mixtures (a currently ongoing effort).

It should be noted that the majority of the studies and efforts have been based on plant-produced asphalt mixtures. A comprehensive study to assess the influence of changes in volumetric and other properties and their relationship to the performance of laboratory-produced asphalt mixtures has not been practical due to limitations in VTRC's technician manpower and workloads.

During the 2018 field trial projects, it was very challenging for VTRC to fabricate specimens on site (i.e., at the plant and without reheating) to meet air voids level and tolerances. To overcome this challenge, the contractor had to compact at least one trial specimen prior to VTRC arrival for sample fabrication. The trial specimen was used to estimate the proper asphalt mixture mass that would result in compacted specimens within the target air void tolerances. Throughout the 2018 and 2019 field trial projects, the following observations were found:

- It is critical to use proper sampling and splitting methods to achieve an appropriate sample size for testing. A performance test can be very sensitive to segregation or alteration in aggregate gradation when no influence is observed on traditional volumetric properties.
- Make sure to measure the maximum theoretical specific gravity on the same asphalt mixture sampled for performance testing and use it for targeting and calculating air voids for compacted specimens.
- Each laboratory will have to establish a procedure to achieve the target air void level. Depending on the technician experience and the approach used, the specimen rejection rate based on air voids for APA, Cantabro, and IDT Cracking can vary among laboratories. The rejection rate can be high initially (~50 percent) but will typically drop to 10 percent or less once the appropriate mass and compaction method were established.

Conducting Inter-Laboratory Studies. VDOT/VTRC has thus far participated in a round robin study initiated by the NCAT, and are leading a separate round robin study for the IDT Cracking test.

A multi-phase round robin study (funded via VDOT UPC #116473) is being conducted by VDOT/VTRC and in collaboration with Virginia Asphalt Association (VAA) for the IDT Cracking test (ASTM D8225-19) using two different types of dense-graded asphalt surface mixtures (initiated in early 2020). A total of 40 laboratories are participating in the round robin resulting in 45 unique data sets (some laboratories have more than one piece of equipment): academia (2), consultants and commercial laboratories (11), contractors (23), State DOTs (2), VDOT/VTRC (2 — one District laboratory and VTRC). Additional VDOT/VTRC laboratories may be able to participate in the round robin study should they acquire the new equipment in time.

Task 5: Establishing Baseline Data.

Conducting Benchmarking studies. Establishing a database of test results helps in understanding the performance of typical dense-graded asphalt surface mixtures and in establishing an initial performance test criteria. The benchmarking study database was used to assess the ability of each performance test to distinguish among various asphalt mixtures; and to determine the ability of each performance test to relate to key asphalt mixture volumetric properties (e.g., air voids, effective binder content). As part of this study the Cantabro test, APA rut test, and four different cracking performance tests were evaluated using typical plant-produced asphalt mixtures. A performance test that does not relate to any of the volumetric properties was discarded from further evaluation. The following summarizes the findings from this study:

Benchmarking studies were used to assess various performance tests and set initial test criteria.

- Cantabro results were moderately correlated with only air voids and VFA.
- The APA rut results showed good correlations with air voids and VFA. Only moderate correlations were observed between APA rut depth and the dust-to-binder ratio, and percent passing the 12.6- and 9.5-mm sieves.
- The OT results were analyzed using three methods: an averaging method, the New Jersey (NJ) method, and the Texas DOT (TxDOT) method. The TxDOT method resulted in the lowest COV, followed by the NJ method and averaging method. Each method resulted in a different average number of cycles until failure. The averaging and NJ methods indicated that OT number of cycles until failure were positively correlated with binder content (coefficients of correlation of 0.79 and 0.80, respectively) and effective binder content (coefficients of correlation of 0.82 and 0.80, respectively); weaker correlations (0.66 and 0.61) were seen for the TXDOT method results. Thus, it was clear that the analysis method influenced the sensitivity of the OT to volumetric properties.
- In the case of the I-FIT test, minimal relationships were found between the flexibility index values and the studied properties in general. A correlation analysis found moderate relationships between the flexibility index and the asphalt mixture bulk and maximum theoretical specific gravities, and aggregate effective and bulk specific gravities.
- The N_{flex} factor values showed almost no relationship with the evaluated volumetric properties. Thus, the test was excluded from the PMD–Phase I study.

- The IDT Cracking test showed moderate correlations between the cracking tolerance index and binder content, air voids, VFA, effective binder content, and film thickness; no correlations were found with VMA or sieve sizes.

Similarly, a database of monotonic loading-based IDT surrogate tests (i.e., high-temperature IDT strength, IDT Cracking, and Marshall stability) is being developed by VTRC. VDOT is planning on testing plant-produced surface asphalt mixtures with A and D designations starting this paving season. The test results will be analyzed to assess test repeatability and ability to discriminate and rank asphalt mixtures based on their rutting performance. Correlations to APA test measurements will also be established; thus, allowing the development of performance test criteria for the IDT-based surrogate tests.

Conducting Shadow Projects. In 2019, the study Balanced Mix Design for Asphalt Mixtures: High RAP Field Trials (VDOT UPC # 115763) was initiated to develop field trials for the High RAP content surface asphalt mixtures designed using performance criteria. The study also involved the assessment of materials, production, and construction processes; and the efficacy of the special provision developed to support the use of BMD. VDOT currently has general guidelines for project selection of BMD in which the project includes at least 4,000 tons of placed asphalt mixture. These will be further developed in the future. The contractor participation in the field trials has been thus far voluntary.

In 2019, two projects were completed by two separate contractors. Each project involved two different roadways where the same asphalt mixture was applied (less than a 1,000 ton of asphalt mixture was placed on each of the project sections). One of the projects included three sections with 40 percent RAP and a combination of different PG asphalt binders and an RA. The project included two control sections with 30 percent RAP and different PG asphalt binders. The second project included only 26 percent RAP but involved two different types of RAs with asphalt mixtures designed in accordance with the special provision for BMD surface asphalt mixtures.

According to the special provisions for BMD and High RAP content surface mixtures, performance testing during production is to be conducted at the frequencies shown in table 39. The contractor is required to fabricate and provide VDOT with specimens for Cantabro and IDT cracking testing; and VTRC with specimens for APA testing. VDOT may require that production be stopped until corrective actions are taken by the Contractor when any performance tests fail to meet the criteria specified in table 37.

Table 39. VDOT Production Testing Frequency.¹

Entity	Gradation/AC	Volumetrics	APA Rutting	Cantabro	IDT Cracking
Producer	500 tons	500 tons	–	500 tons	500 tons
VDOT	500 tons	1,000 tons	–	1,000 tons ²	1,000 tons ²
VTRC	500 tons	500 tons	500 tons ²	500 tons (reheat)	500 tons (reheat)

–Not applicable.

¹With a minimum of 1 sample per day, per entity, per test.

²Minimize any cooling of the plant-produced asphalt mixture and bring the specimens to the compaction temperature and compact immediately to the required specimen size. Specimens are fabricated and provided to VDOT by the contractor.

Performance test results have not been tied to any pay factors yet. An understanding of the influence of asphalt plant production variability and tolerances (e.g., binder content, gradation) on the performance test results of plant-produced asphalt mixtures is needed. Also, contractors need to know what corrective changes to make in order to bring a produced asphalt mixture back into compliance. Accordingly, VTRC has an on-going study (Impact of Production Variability on Balanced Mix Design in Virginia [UPC # 116425]) to assess the influence of production variability on the performance test responses of asphalt mixtures. The study involves the reproduction of plant-produced asphalt mixtures in the laboratory according to the approved JMF as well as at the upper and lower asphalt plant tolerances for gradation and binder content. This study is an essential step in the validation of the performance test criteria, and in developing allowable tolerances for acceptance.

Analyzing Production Data. Based on contractors' experience with field trial projects thus far, the following observations were made:

- In general, an increase in binder content by a couple tenths improved IDT cracking significantly without jeopardizing APA rut depths. The use of RA at the proper dose with 40 percent RAP also helped in improving the asphalt mixture performance. These changes were coupled with the use of different sources of manufactured sand (even sometimes had to add more sand and cut down on the No. 8 sieve) or some minor changes in aggregate blend gradation. Making the aggregate gradation coarser on the coarse side and finer on the fine side increased the VMA and allowed more room for asphalt binder in the mixture. Increasing fines in the asphalt mixture, along with the increase in binder content, increased the mastic content in the mixture and improved cracking resistance.
- Changes to asphalt mixtures to get acceptable performance testing values were material specific. For instance, the same practice that seemed to work well for a given asphalt mixture was not necessarily effective for a mixture produced using other sources of materials. This can be challenging for asphalt mixture suppliers possessing several quarries and aggregates with different specific gravities, absorptions, and particle shapes.
- In general, performance tests, and in particular IDT Cracking, were sensitive to changes in the properties of utilized RAP material. Thus, a proper stockpile management plan and process control for RAP properties was found to be critical; thus, allowing for making appropriate adjustments to the asphalt mixture during production whenever significant changes in RAP properties were detected.
- Plan ahead for enough time to conduct asphalt mix designs following the BMD approach. The critical part of the BMD approach was to make sure the asphalt mixture passed the cracking performance test criteria first, before moving forward with the evaluations in APA and Cantabro.
- Specimen and test temperatures were found to affect Cantabro test results. For instance, a failing asphalt mixture may end up passing the Cantabro loss criteria if left to run overnight during a drop in the laboratory ambient temperature.
- Plant-produced asphalt mixtures exhibited cracking tolerance indices that were higher than those observed for laboratory-produced asphalt mixtures during design. This needs to be addressed either by adjusting the test criteria, or by applying a correction factor between the test results of laboratory- and plant-produced asphalt mixtures.

As production data was analyzed, contractors provided valuable input.

- In order to make sure that the asphalt mixture is in compliance during production, a good practice was to have a dry run of the asphalt mixture production the day before the actual construction of the field trial project. Asphalt suppliers need to start establishing a reference database for all of their produced asphalt mixtures.

Contractors were fabricating as much as 48 compacted specimens a day that comprised 4 APA, 3 Cantabro, and 5 IDT Cracking specimens per lot for 4 sampling lots. Contractors expressed interest in and support for the IDT Cracking testing because it is a quick test and results are instantaneous; fabrication and testing was as much as 20 specimens a day. The bottleneck in the process during production was the time needed to cool down compacted specimens before bulking; specimens were put for couple hours in front of a fan to dry them faster (a small air conditioning unit was also used). This pushed back testing, in particular APA, to the next day; on future trial projects, an accelerated cooling method is needed. The very limited production (only 75 tons per lane per day) on the HVS test sections was noted; however, that was judged to not be representative of Virginia’s BMD trials; that project was not set up to be a production contract (where a decision was made to incorporate a BMD trial) but rather a series of specific different trials.

Determining How to Adjust Asphalt Mixtures Containing Local Materials. A comprehensive study was not conducted to assess the changes of asphalt mixture properties to identify the relationship to the performance test results due to limitations in VTRC’s technician manpower and workloads (i.e., laboratory-produced asphalt mixtures are not practical). However, this was done in an effective manner on plant-produced asphalt mixtures by testing local materials by using the database from the benchmarking study. Additionally, VDOT/VTRC relied on available relevant literature to assist.

Task 6: Specifications and Program Development.

Developing Pilot Specifications and Policies. VDOT has a creative method for selection of the BMD approach. At the time when a pilot project is proposed, the contractor may select *Approach A Volumetric Design with Performance Verification* and/or *Approach D Performance Design*; contractors are encouraged to do both, but only one was required per the special provision. For the 2022 paving season, VDOT has transitioned to: (a) advertising a small number of pilot projects with BMD included; and (b) requiring the asphalt mixtures to be designed to conform to both performance criteria and a slightly-modified-from-standard volumetric criteria. The special provision for Balanced Mix Design (BMD) Surface Mixtures Designed Using Performance Criteria was revised (dated October 26, 2021) and used for the 2022 BMD projects.⁽⁸⁹⁾ The specification covers the requirements and materials used to produce surface asphalt mixtures designed to meet the Performance + Volumetric Optimized (BMD P+VO) criteria.

Initially, a contractor volunteers to participate in a pilot project and selects Approach A or D. Two years later BMD surface mixtures are designed to meet the Performance + Volumetric Optimized criteria.

The importance of having more than one round of BMD pilot projects was discussed among stakeholders so that contractors that are not ready to get involved immediately can trust that they will have more opportunities before full implementation by VDOT. Contractors will need time to

gain experience and become familiar and comfortable with the process before full implementation.

Task 7: Training, Certifications, and Accreditations.

Developing and/or Updating Training and Certification Programs. Training technicians on the procedures and analysis of test results is necessary. In 2020, most of the VDOT/VTRC effort had been focused on testing and analysis to gain trust and comfort with the performance tests. Training videos made available by certain equipment manufacturers have also been used.

No formal training activities had been conducted by VTRC at the time of the site visit, but instructions and guidance related to sample fabrication, preparation, testing, and data analysis were provided to contractors, consulting firms, and asphalt mixture suppliers. Towards the end of 2019, VAA conducted a hands-on training workshop for laboratory testing and asphalt mix design and adjustments.

VDOT envisioned a statewide training and certification program for agency and industry on BMD approaches. Informal discussions continue with stakeholders at the VDOT “BMD Advisory Committee.” During 2021, certification classes were conducted for approximately 100 technicians (both VDOT and Contractor staff) who were trained on BMD mix design and testing. The training program is anticipated to be further developed and in 2023 is expected to become part of the standard technicians’ certification program that is currently established under the Virginia Education Center for Asphalt Technology (VECAT). VTRC submitted a proposal to help fund these goals to the State Transportation Innovation Council (STIC), since the purpose of FHWA’s STIC Incentive Program is to advance innovative technologies and/or methods into statewide practices.

Task 8: Initial Implementation.

Ideally, VDOT would have preferred to research the aging effects of High RAP as well as RA options, prior to incorporating a High RAP element into their BMD research. However, VDOT proceeded to implement pilot special provisions for both non-high-RAP BMD and for high RAP content (40% or more) surface mixtures designed using performance criteria, due to keen interest on the part of industry, and the need to have enough field work to support the needed research on high RAP variability. Since that time, as a part of BMD research, both conditions (“regular” RAP limits and “High” RAP) have been evaluated against the BMD performance tests and VDOT thresholds. As of 2022, VDOT has undertaken research on critical aging and on RAs, so for now, VDOT is no longer including higher RAP mixes in their BMD pilot projects. However, when this ongoing critical aging and RA research is completed, VDOT will make decisions about the viability of allowing high RAP contents as part of their future BMD specifications.

Most of the effort has focused on applying performance testing to the design of surface asphalt mixtures. Additional efforts will need to consider the feasibility of using performance testing for asphalt mixture acceptance during production. Thus, monotonic load-based tests including high-temperature IDT, IDEAL-RT, Marshall stability, and IDT Cracking are being evaluated for possible use as a surrogate performance tests during production. In the meantime, volumetric requirements can still be used for acceptance given concerns related to timeliness and

responsibility for testing, single and multiple operator variabilities in test results, and the need for additional resources.

OBSERVED BENEFITS

The use of BMD on trial field projects allowed contractors to utilize innovative and recycled materials (e.g., RAP, RAs, PG of asphalt binders) in order to produce asphalt mixtures that are in compliance with VDOT specifications. Furthermore, the traditional volumetric-based mix design did not provide optimum performance for asphalt mixtures with high RAP content. Performance testing helped in designing asphalt mixtures with high RAP contents that resulted in greater resistance against primary modes of distress (i.e., rutting, durability, and cracking); thus, allowing for the production of economical and environmentally friendly asphalt mixtures without jeopardizing performance.

The asphalt mixtures designed using the BMD approach were in general easier to compact in the field and to reach target in-place density. More consistent in-place densities were also observed in the BMD sections when compared to control sections (using traditional asphalt mixtures). For example, a BMD test section from the HVS experiment exhibited in-place densities that were on average 1.5 percent higher than those observed on control section; 93–94 percent densities in comparison to 91–93 percent. This observed improvement in the in-place pavement density can lead to more than 10 percent increase in asphalt pavement service life.

FUTURE DIRECTION

VDOT is working on a framework for the full implementation of BMD for design and acceptance. This includes an overall plan describing the steps to move forward with implementation based on current status while identifying and quantifying all potential concerns and how to navigate them in order to overcome.

VDOT envisions a two-part criterion for BMD, one on the initial design and one during production to guarantee that an asphalt mixture has the desired performance properties. A series of studies and activities are needed in order to ensure full implementation of BMD for design and acceptance. Some examples are provided below:

- Increase the number of pilot projects to cover the different materials throughout the State.
- Continue monitoring the field pavement performance and use information to validate and modify as needed the established initial performance test criteria.
- Select and implement surrogate performance tests as an alternative to APA that can be used during production.
- Develop RA evaluation process for acceptance to facilitate its proper use in BMD approach.
- Implement an application-based performance test criterion based on traffic level and asphalt mixture type (i.e., SM, IM, BM, or SMA).
- Investigate and develop a representative long-term oven aging protocol for asphalt mixtures to simulate in-service aging. The long-term aging method is anticipated to be part of the asphalt mix design method and not acceptance.
- Establish necessary precision and bias statements for utilized performance tests.

- Understanding and quantifying the influence of asphalt plant production variability and tolerances (e.g., binder content, gradation) on the performance test results of plant-produced asphalt mixtures.

The full implementation effort needs to be supplemented with proper communication, training and education activities. Contractors will need to be educated on what changes can be made to the asphalt mixture composition or proportions in order to make informed and cost-effective decisions to improve performance and meet applicable specification limits.

CHAPTER 9 POSITIVE PRACTICES, LESSONS LEARNED, AND CHALLENGES

Successful practices documented from these virtual site visits were collected and synthesized into an overall process of implementing BMD as part of mix design approval and QA. These practices were compiled from the positive practices, lessons learned, and challenges from lead States that have gone through BMD implementation. This process comprises eight major tasks that were established in collaboration with NCAT based on concurrent activities (e.g., BMD regional workshops). Practices from some of the States for each of the tasks are summarized below.

General Comments

- There are four approaches to BMD. As more experience and confidence are gained with one approach, an agency can evolve to a different approach.
- Implementation of BMD could be as big of a change as implementation of Superpave binder and mixture, if not bigger.
- BMD is not a cure all. Thickness design, existing pavement distresses (e.g., mitigating reflective cracking), construction troubleshooting (e.g., weak subgrade), need to be addressed.
- Tasks are not necessarily sequential and may be accomplished concurrently. Depending on the goal(s), some tasks may not be necessary.
- The following aspects can be challenging to the implementation of BMD:
 - Development and implementation of BMD will require resources: research, equipment, and manpower.
 - Full implementation of BMD will likely take several years and requires continuous improvements.
 - BMD performance tests may not be able to fully replace current acceptance testing.
 - Large variability in the BMD test results exceeding conventionally accepted repeatability of measurements.
 - General resistance from the asphalt industry to change.

Task 1 is
“starting with
the “why.”

Task 1: Motivations and Benefits of BMD

The first step for BMD implementation is for the stakeholders, and in particular for top management, to understand why a new approach to asphalt mixture design and acceptance is needed and the associated benefits expected with the change. This will be critical for securing the necessary management support and commitment from both the State DOT and industry to invest in full implementation of BMD. Table 40 summarizes examples of practices from States for Task 1.

Task 2 is
“how to get
started.”

Task 2: Overall Planning

This task is concerned with understanding the overall implementation process, defining and setting a State DOT’s goals, and determining the resources necessary to achieve those goals with a realistic timeline. Achieving those goals involves coordinated efforts and partnership with stakeholders. Table 41 summarizes examples of practices from States for Task 2.

Task 3 is “one of the longer tasks.”

Task 3: Selecting Performance Tests

For each type of asphalt pavement distress, there are several possible mixture performance tests that can be considered for use in asphalt mix design and acceptance. The selection of performance tests can draw upon information in the new AASHTO provisional standards for BMD (which are voluntary and non-mandatory standards), the final report from NCHRP 20-07/Task 406, and the newly released report by Hajj et al. (2019) titled Index-Based Tests for Performance Engineered Mixture Designs for Asphalt Pavements.^(2,17) Table 42 summarizes examples of practices from States for Task 3.

Table 40. Examples of Practices from States: Motivations and Benefits of BMD.

Motivations	Benefits
<ul style="list-style-type: none"> • Building LLAPs that could last more than 30 years using PRS and ME design to tie mixture and thickness designs together (Caltrans). • Simplifying the BMD approach to allow higher recycled content that could be applied to standard projects statewide (Caltrans). • Performance tests were implemented due to an immediate need to address premature failures as a result of the use of recycled mixtures (IDOT). • BMD was implemented to address premature failures and allow the use of innovative and recycled material (LaDOTD). • To address an immediate need of durability and raveling issues that went beyond volumetric properties (MaineDOT). • Performance tests were used to design asphalt mixtures to specifically address durability and cracking to increase pavements’ longevity. Adjusting gyrations and volumetric properties were not sufficient to address performance concerns of durability and cracking (NJDOT). • There was an immediate need to address the observed premature failures of asphalt pavement as a result of the use of recycled materials in asphalt mixtures; and there was a desire to use higher quantities of RAP (TxDOT). • Implementation of BMD was to support the use of higher quantities of recycled materials (VDOT). 	<ul style="list-style-type: none"> • Personal testimony from District 6 was a powerful way to document benefits of implementing performance tests (IDOT). • Fewer cases of premature failure were observed resulting in an estimated cost savings of \$7.5 million per year (Maine DOT). • The use of performance tests with specialty mixtures was a significant reason for the overall improvement of the road network (NJDOT). • Cost savings from increasing RAP use was a motivation to implement BMD (TxDOT).

Table 41. Examples of Practices from States: Overall Planning.

Subtasks	Examples
Identification of Champions.	<ul style="list-style-type: none"> • The champion gained management support for equipment purchases, additional staffing, and laboratory space (MaineDOT). • One of the roles of the champion was to coordinate between all the different groups within the DOT (NJDOT).
Establishing Stakeholder Partnerships.	<ul style="list-style-type: none"> • Two stakeholder groups were formed. The BMD Advisory Committee handled the executive-level decisions. The BMD Technical Subcommittee handled the technical decisions (VDOT).
Doing Your Homework.	<ul style="list-style-type: none"> • There was a long history with using performance tests (LaDOTD, TxDOT). • Differences between performance testing related to specimen fabrication and testing times impacted the decision for the type of performance test (MaineDOT). • Research with academia is a key to identifying solutions to improve pavement performance (NJDOT). • Performance tests were implemented in a phased manner. <ul style="list-style-type: none"> ○ The HWTT was implemented in 2014 (Caltrans). ○ The HWTT was implemented in 2012 and the I-FIT was implemented in 2021 (IDOT). ○ The HWTT was implemented in 2004 and the OT was implemented in 2014 (TxDOT).
Establishing Goals.	<ul style="list-style-type: none"> • All projects for mix design and acceptance (IDOT, LaDOTD). • All interstate and high investment projects (MaineDOT). • The initial goal was implementation of specialty mixtures. Now the goal is evolving to include dense-graded mixtures (NJDOT, TxDOT).
Mapping the Tasks.	<ul style="list-style-type: none"> • For LLAPs, comprehensive and detailed research roadmaps were developed for asphalt mixture and thickness designs. Roadmaps included tasks to be completed under Concept, Research, Development, and Implementation (Caltrans). • Mapping was done with simple, “big-picture” tasks (VDOT).
Identifying Available External Support.	<ul style="list-style-type: none"> • Support from academia was a key. (Caltrans, IDOT, LaDOTD, NJDOT, TxDOT).
Developing an Implementation Timeline.	<ul style="list-style-type: none"> • A timeline was used to guide a phased implementation of projects (IDOT, VDOT). • With a long history of performance testing, BMD implementation was condensed into a few years (LaDOTD).

Table 42. Examples of Practices from States: Selecting Performance Tests.

Subtasks	Examples
Identifying Primary Modes of Distress.	<ul style="list-style-type: none"> • Rutting and reflective cracking were the distresses that needed addressing (IDOT). • Rutting and cracking were the distresses that needed addressing (LaDOTD). • Raveling, rutting and cracking were the primary asphalt pavement modes of distress (Maine DOT). • Cracking from Superpave mixtures and composite pavements needed addressing (NJDOT). • Cracking from mixtures with low binder contents and high RAP contents needed addressing (VDOT).
Identifying and Assessing Performance Test Appropriateness.	<ul style="list-style-type: none"> • The SCB was fundamentally derived from fracture mechanic principles (LaDOTD). • The top factors for selection of a performance test for asphalt mix design were different than those for production (NJDOT). • Multiple performance tests were evaluated through a formal benchmarking research study (VDOT).
Validating Performance Tests.	<ul style="list-style-type: none"> • Validating asphalt mixture performance tests was accomplished with multiple techniques that included: ME analyses, ALF, LTPP SPS-5 sections, PMS data, monitoring pavement performance of pilot projects, forensic studies (Caltrans, IDOT, LaDOTD, MaineDOT, NJDOT, TxDOT).

Task 4 is “let’s get going.”

Task 4: Performance Testing Equipment: Acquiring, Managing Resources, Training, and Evaluating

This task involves acquiring equipment for performance testing, managing available resources, conducting initial training, evaluating performance tests, and conducting ILS. Table 43 summarizes examples of practices from States for Task 4.

Task 5 is “addressing field aspects.”

Task 5: Establishing Baseline Data

Establishing baseline data is critical for the development of performance test criteria and related specifications. The baseline data will help both State DOT and industry gain confidence that the test criteria used for asphalt mixture design and/or acceptance are appropriately set. Ultimately, the test criteria can be established from data sets from a series of tasks that may include: Subtasks 3.3, 4.5, 5.2, 5.4, and 6.5. Table 44 summarizes examples of practices from States for Task 5.

Table 43. Examples of Practices from States: Performance Testing Equipment.

Subtasks	Examples
Acquiring Equipment.	<ul style="list-style-type: none"> • Being decentralized, a bulk equipment purchase was used to equip each of the districts (IDOT). • The HWTT was in each of the districts. The SCB was only at LTRC (LaDOTD). • Performance testing is only done at the central laboratory (MaineDOT, NJDOT).
Managing Resources.	<ul style="list-style-type: none"> • Additional staff was hired, and additional space was needed (MaineDOT). • Finding laboratory space was challenging (NJDOT). • An active MPL exists for laboratories approved to perform the HWTT (TxDOT). • Staffing and laboratory space are being evaluated to determine the number of BMD projects (VDOT).
Conducting Initial Training.	<ul style="list-style-type: none"> • Technicians reported that instructional videos were very helpful (IDOT). • LTRC hosted a workshop with classroom and lab components (LaDOTD). • Efficiencies were found in predicting the sample weight to obtain the target air voids and identifying technician responsibilities (MaineDOT).
Evaluating Performance Tests.	<ul style="list-style-type: none"> • A disconnect was revealed between performance test data from LPLC and PPLC results (Caltrans, IDOT). • Long-term aging protocols for the I-FIT were developed through a research project (IDOT). • Test results from different equipment manufacturers can produce different results (LaDOTD, NJDOT). • Robust procedures were needed for the calculation, analysis, and reporting of results (MaineDOT).
Conducting ILS.	<ul style="list-style-type: none"> • Annual round robins were conducted which provided valuable information on test variability (IDOT). • High variability from specimen fabrication resulted in creation of a specimen fabrication QC form (LaDOTD). • Multiple round robins led to improved specimen fabrication and testing procedures (MaineDOT). • Annual round robin studies were used to determine repeatability. They also allowed users to gain trust and comfort with the performance tests (NJDOT).

Table 44. Examples of Practices from States: Establishing Baseline Data.

Subtasks	Examples
Reviewing Historical Data.	<ul style="list-style-type: none"> • A long history of performance test results was valuable to tie properties to field performance (LaDOTD).
Conducting Benchmarking Studies.	<ul style="list-style-type: none"> • Benchmarking has been used to create a database with over 3,000 test sets that has resulted in valuable analyses to understand the sensitivity of the test (IDOT). • Benchmarking studies were used as an initial check of the test criteria (LaDOTD). • Benchmarking and other States’ studies allowed for setting the initial test criteria (MaineDOT). • A large database of performance test results was established for a wide variety of mixtures used throughout the State (NJDOT). • Benchmarking studies were used to assess various performance tests and set initial criteria (VDOT).
Conducting Shadow Projects.	<ul style="list-style-type: none"> • Shadow projects were an important part of the implementation plan (IDOT).
Analyzing Production Data.	<ul style="list-style-type: none"> • Baseline data was analyzed from pilot projects (Caltrans). • Results from LPLC and PPLC mixtures were different and potential causes were identified (IDOT). • Plant trial batching was a critical step in mixture verification (TxDOT). • As production data was analyzed, contractors provided valuable input (VDOT).
How to Adjust Asphalt Mixtures.	<ul style="list-style-type: none"> • A process was used to adjust mixtures to meet performance test requirements in a systematic manner for efficiency (Caltrans). • Calibration of the plant’s weigh bridges became more important (LaDOTD). • A large database including aggregates from over 200 sources was used to examine trends for adjusting mixtures (TxDOT).

Task 6 is “writing the specification.”

Task 6: Specifications and Program Development

A State DOT needs to develop preliminary mix design and/or acceptance criteria that will be used in developing specifications prior to the pilot projects. A State DOT may use the information gathered from the field validation experiments (Subtask 3.3), variability studies (Subtask 4.5), and established baseline data (Task 5) to establish performance test criteria. Furthermore, information from the State DOT’s existing QA program can be used to select the appropriate quality measures, AQCs, and preliminary AQC specification limits for each test method. In this task, risk analyses can also be used to evaluate the preliminary acceptance criteria. In addition, the information from the aforementioned tasks can also be used to select appropriate quality characteristics for QC.

Based on the goals set by a State DOT (Subtask 2.4), there are a number of options of how acceptance and quality control testing can be handled for acceptance during mixture production. Examples are shown in table 45. Both NJDOT and TxDOT are exploring the use of surrogate test(s) for acceptance during production with correlation to asphalt mixture design performance test(s). The benefits for using surrogate performance tests include: minimal investments by both the State DOT and industry; more tests can be completed within normal working hours; and reduced overall need for staffing and quick turnaround time. However, surrogate tests for acceptance may require correlation/calibration with more fundamental performance tests. These benefits are very test specific depending on which surrogate performance test is selected. Table 46 summarizes examples of practices from States for Task 6.

Table 45. State DOT Examples for Asphalt Mixture Acceptance during Production.

Acceptance	Example State DOT
Volumetric properties.	Caltrans and LADOTD.
Surrogate performance tests correlated to mixture design approval tests.	NJDOT and TxDOT.
Actual performance tests used during mixture design.	IDOT, NJDOT, and MaineDOT.
Performance tests with pay adjustment factors.	NJDOT.

Table 46. Examples of Practices from States: Specifications and Program Development.

Subtasks	Examples
Developing Pilot Specifications and Policies.	<ul style="list-style-type: none"> • Specifications and policies for the HWTT were created and reviewed prior to using them on pilot projects (MaineDOT). • Detailed specifications were prepared, which included the use of a test strip and field-testing frequencies (NJDOT). • BMD for dense-graded asphalt mixtures was implemented on a voluntary basis. The goal was to have 20 projects over 2 years (TxDOT). • BMD pilot projects were optional for the contractor. The contractor would select Approach A or D (VDOT). • The specification calls for a minimum of 40 percent RAP and allows for RAs (VDOT).
Conducting Pilot Projects.	<ul style="list-style-type: none"> • Pilot projects were introduced gradually and started with one per district (IDOT). • A pilot project was conducted in 6 of the 9 districts. Full implementation followed 3 years later (LaDOTD).
Final Analysis and Specification Revisions.	<ul style="list-style-type: none"> • The specification addresses performance testing during mix design and production (IDOT). • Performance testing was successfully implemented for mix design and there is now interest in using them for acceptance (NJDOT). • There is interest in exploring the use of surrogate performance testing (NJDOT, TxDOT).

Task 7 is “getting close to institutionalization.”

Task 7: Training, Certifications, and Accreditations

Following the completion of the pilot projects and prior to initial implementation, a State DOT needs to formalize the changes to its existing technician and laboratory qualification programs, and determine how training will be provided for personnel already qualified for the previously used acceptance tests. Table 47 summarizes examples of practices from States for Task 7.

Table 47. Examples of Practices from States: Training, Certifications, and Accreditations.

Subtasks	Examples
Developing Training and Certification Programs.	<ul style="list-style-type: none"> • Performance tests are part of the standard technician certification program (IDOT, TxDOT). • Training contractor staff on their own equipment in their own laboratory environment was extremely helpful (Caltrans).
Establishing Laboratory Accreditation.	<ul style="list-style-type: none"> • Central laboratories are accredited and as a local practice district laboratories may be accredited. Technicians doing acceptance testing are required to participate in an annual proficiency program (LaDOTD).

Task 8 is “not the finish line, but the starting point.”

Task 8: Initial Implementation

Prior to implementation of the performance requirements, it is essential that the State DOT adequately communicate the changes and new requirements to both industry and agency personnel. This technology transfer can be done through the use of webinars, face-to-face meetings, and workshops. It can also be supported by having “implementation teams” that can help both contractors, consultants, and State DOT personnel address problems, interpret specification requirements, etc. It is important to integrate a feedback loop into the process to ensure and encourage communication and regular feedback from the various stakeholders, and to help identify areas for future adjustment and improvement. Feedback loops help a State DOT to have more coordinated, collaborative, and committed effort towards full implementation of BMD and performance specifications. This involves continuous monitoring of test sections and early projects that were built as part of this overall BMD implementation effort.

The scope for project selection may need to be developed prior to implementation of BMD and specifications. The scope is function of the target goals for the BMD program and can consider the project investment level, the rehabilitation type, the project highway functional classification and traffic level, the project length and asphalt tonnage, the pavement layer, etc. The scope for project selection needs to be regularly evaluated and updated based on the feedback loop and consider available resources within a State DOT.

Examples of practices from States for Task 8 include:

- The implementation was very well planned and systematic (IDOT).
- Initial implementation resulted in fewer premature pavement failures. About half of the asphalt mixtures submitted needed modification to pass the HWTT (MaineDOT).

- The initial goal was to use performance testing in the implementation of specialty mixtures, about 10 to 15 percent of the program. Once accomplished, the next step will be implementation for dense-graded asphalt mixtures (NJDOT).

CHAPTER 10 RESEARCH AND DEPLOYMENT OPPORTUNITIES

A list of research and deployment topics were identified during the virtual site visits that were grouped into three common themes which are: Research, Deployment, and Technical Support.

Research:

- Evaluation and optimization of laboratory fabrication and conditioning of asphalt specimens for performance testing including the effect of specimen size, shape, reheating, conditioning, and aging.
- Evaluation of cyclic SCB test for determining the asphalt mixture resistance to fatigue cracking under repeated loading.
- Understanding and quantification of the influence of asphalt plant production variability and tolerances (e.g., asphalt binder content, gradation) on the performance test results of plant-produced asphalt mixtures and its implication on specifications. This will provide contractors with the information needed to control their produced asphalt mixture and to make the necessary changes to bring them into compliance. It will also provide State DOTs with proper justification to make any necessary and reasonable changes in production tolerances.
- Examination and assessment of the surface characteristics (e.g., skid resistance, smoothness) of asphalt mixtures with high recycled materials.
- Investigation of changes and improvements that can be made to the performance tests of asphalt mixtures to reduce test variability.

Deployment:

- Facilitation of a BMD peer exchange to share the lessons learned from those State DOTs that have laid much of the ground work for implementing and transitioning to a BMD procedure, to provide advice on the transition to those State DOTs just starting or thinking about the transition, and to highlight the challenges with using a BMD.
- Identification of changes that can be made by contractors 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.). These changes are likely to be asphalt plant and material specific (as well as agency specific), driven by differences in the implemented specifications. 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.
- Development of a guideline illustrating and outlining the process for materials and information that need to be collected for initial implementation of performance testing. Such a guideline is imperative for State DOTs that are looking into establishing and implementing performance testing and BMD.
- Development of 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.

- Development and delivery of training materials and hands-on workshops on testing, analysis, and interpretation of performance test results including the influence of changes in asphalt mixture components, composition, and proportions during design or production on performance.

Technical Support:

- Establishment of ways to provide continuous support for ruggedness studies of new and existing performance tests.
- Continue to provide State DOTs with technical assistance related to BMD implementation including the offer to review and analyze BMD baseline data as well as sharing experiences, lessons learned, and challenges.

CHAPTER 11 SUMMARY

Several tasks and subtasks for the implementation of BMD for asphalt mix design and production acceptance are presented in this report. Each State is likely to start at a different task (e.g., starting from scratch, already implemented one performance test, etc.) and end at a different task (e.g., mix design only, acceptance, performance prediction, etc.). With varying goals and differences in available resources for implementation (e.g., time, funding, academia support, etc.), each State is also likely to take a different path from start to end. The information presented in this report is provided to assist State DOTs in the efforts to plan for a successful implementation of BMD into their asphalt pavement program.

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