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

Louisiana Department of Transportation & Development (LaDOTD)

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACI	alligator cracking index
ADI	Asphalt District Inspector
ADT	average daily traffic
ALF	Accelerated Load Facility
AMPT	Asphalt Mixture Performance Tester
ASTM	American Society for Testing and Materials
DOT	Department of Transportation
BMD	Balanced Mix Design
COV	coefficient of variation
DEM	discrete element method
FHWA	Federal Highway Administration
GPC	gel permeation chromatography
HMA	hot-mix asphalt
ILS	interlaboratory study
JMF	job mix formula
LA	Louisiana
LA-PMS	Louisiana pavement management system
LaDOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
LWT	loaded wheel tester
MEPDG	Mechanistic-Empirical Pavement Design Guide
NCHRP	National Cooperative Highway Research Program
NMAS	nominal maximum aggregate size
OBC	optimum asphalt binder content
OGFC	open graded friction course
OT	Overlay test
PBS	performance-based specifications
PCC	Portland cement concrete
PEP	Performance Engineered Pavements
PG	performance grade
PWL	percent within limits
RAP	reclaimed asphalt pavement
RAS	reclaimed asphalt shingles
RCI	random cracking index
SCB	semi-circular bend
SHA	state highway agency
SMA	stone matrix asphalt
U.S.	United States
VFA	voids filled with asphalt
VMA	voids in mineral aggregate
WMA	warm-mix asphalt

BACKGROUND

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

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

In August 2018, the National Cooperative Highway Research Program (NCHRP) Project 20-07/Task 406, *Development of a Framework for Balanced Mix Design*, included a draft American Association of State Highway and Transportation Officials (AASHTO) Standard Practice for Balanced Design of Asphalt Mixtures with a nine step process for evaluating and fully-implementing a performance test into routine practice. The provisional AASHTO Standard Practice PP 105-20 describes four approaches (A through D) for a BMD process. The following is a brief description of the four approaches:

- ***Approach A—Volumetric Design with Performance Verification***. This approach starts with the current volumetric mix design method (i.e., Superpave, Marshall, or Hveem) for determining an optimum asphalt binder content (OBC). The mixture is then tested with selected performance tests to assess its resistance to rutting, cracking, and moisture damage at the OBC. If the mix design meets the performance test criteria, the job mix formula (JMF) is stablished and production begins; otherwise, the entire mix design is repeated using different materials (e.g., aggregates, asphalt binders, recycled materials, and additives) or mix proportions until all of the volumetric criteria are satisfied.

- ***Approach B—Volumetric Design with Performance Optimization***. This approach is 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. 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, and moisture damage criteria is finally identified as the OBC. In cases where a single binder content does not exist, the entire mix design process needs to be repeated using different materials (e.g., aggregates, asphalt binders, recycled materials, and additives) or mix 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 initial component material properties, proportions, and binder content. The performance test results are then used to adjust either the initial binder content or mix component properties or proportions (e.g., aggregates, asphalt 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 Superpave volumetric criteria.

- ***Approach D—Performance Design***. This approach establishes and adjusts mixture components and proportions based on performance analysis with limited or no requirements for volumetric properties. Minimum requirements may be set for asphalt binder and aggregate properties. Once the laboratory test results meet the performance criteria, the mixture volumetrics may be checked for use in production.

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

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

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

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

OBJECTIVE

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

SCOPE AND OUTCOMES

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

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

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

GENERAL INFORMATION SPECIFIC TO LaDOTD

In fiscal year 2018-2019, LaDOTD placed about 1.63 million tons of asphalt mixture (table 1). 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. The asphalt mixture types and applications are summarized in table 2.

The Section 501 of specifications applies to all asphalt concrete thin lift 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); Coarse Mix applied to all traffic volumes; and Open Graded Friction Course (OGFC) applied to all traffic volumes.

The Section 502 of specifications applies to wearing, binder, and base courses including stone matrix asphalt (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 hot-mix asphalt (HMA) concrete 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 voids in mineral aggregates (VMA) or critical strain energy release rate (Jc).

LaDOTD specifications for asphalt mixtures currently require the loaded wheel tester (LWT) for rutting performance evaluation (Section 501 and Section 502 mixtures) and the semi-circular bend (SCB) test for cracking performance evaluation (Section 502 mixtures only).

Table 1. 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 2. Asphalt Mixture Types Used by LaDOTD.

Specifications	Mixture Types	Applications
Thin Asphalt Concrete Applications (Section 501)	• Dense Mix. • Coarse Mix. • OGFC.	• New and rehabilitation construction. - Dense Mix: traffic volumes less than 3,500 ADT. - Coarse Mix: all traffic volumes. Can be substituted in place of Dense Mix without change order. - 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. • Used as a finish course. - Thin lift asphalt mixture placed over a 502 asphaltic concrete pavement of a Portland cement concrete (PCC) pavement.
Asphalt Concrete Mixtures (Section 502)	• Wearing course. • Binder course. • Base course. • SMA.	• New and rehabilitation construction. - 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). Required on all interstate wearing courses with traffic volumes greater than 35,000 ADT.

With the significant increase in traffic volume on highways, asphalt pavements built with acceptable levels of quality according to specifications have started to experience more frequent premature failures or did not perform as originally intended. Furthermore, the increase interest in using rubber-modified asphalt binders, reclaimed asphalt pavement (RAP), and warm-mix asphalt (WMA) technologies made it challenging for LaDOTD to adequately assure the long-term performance of asphalt pavements with its conventional quality 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.

Overall, LaDOTD employed a phased-in approach for BMD and performance tests implementation. The Louisiana Transportation Research Center (LTRC) initiated several research studies in 2011 to develop performance-based specifications (PBS) 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. The LWT and SCB performance tests were implemented to assess the stability and durability of asphalt mixtures during the design and acceptance process.

BMD APPROACH

In 2018, LaDOTD implemented additional changes/improvements to Sections 501 and 502 of the 2016 standard specifications. Figure 1 shows a flowchart of the overall BMD for Section 502 Asphalt Concrete Mixtures that highlights the major steps for undertaking a mixture design according to LaDOTD specifications (2018 amendments). The requirements for asphalt binder performance grade (PG), volumetric design, and performance testing for Sections 501 and 502 asphalt mixtures are summarized in table 3 to table 5.

Performance testing requirements are provided as a function of traffic condition as well as asphalt mixture type and location within the asphalt pavement structure. LaDOTD restrict the use of reclaimed asphalt shingles (RAS) in any of its asphalt mixtures.

The LaDOTD's BMD for designing asphalt mixtures and approving job mix formulas (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% for Dense Mix, 7% for Coarse Mix, and 18–24% for OGFC. Section 502 asphalt mixtures are designed at 30 to 65 gyrations to a design target air voids of 3.5%.

The contractor submits the proposed JMF electronically through LaPave Online at least 7 days prior to use for review and approval by LaDOTD (http://wwwapps2.dotd.la.gov/engineering/lapave/, http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Materials_Lab/Pages/ExcelForms.aspx). At a minimum, the JMF must include the recommended materials proportions, extracted gradation, recommended mixing and compaction temperatures, and supporting design data. Asphalt mixture will not be produced until the proposed JMF has been accepted.

Once accepted, LaDOTD and the contractor will validate the JMF by jointly testing the plant-produced asphalt mixture, which has to meet all 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 asphalt 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 quality control 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 sublot. During the validation process or when a new asphalt binder source is used, the Asphalt District Inspector (ADI) will collect a sample of loose plant-produced asphalt mixture and a sample of asphalt binder that will be sent to the LaDOTD central materials laboratory for gel permeation chromatography (GPC) testing.

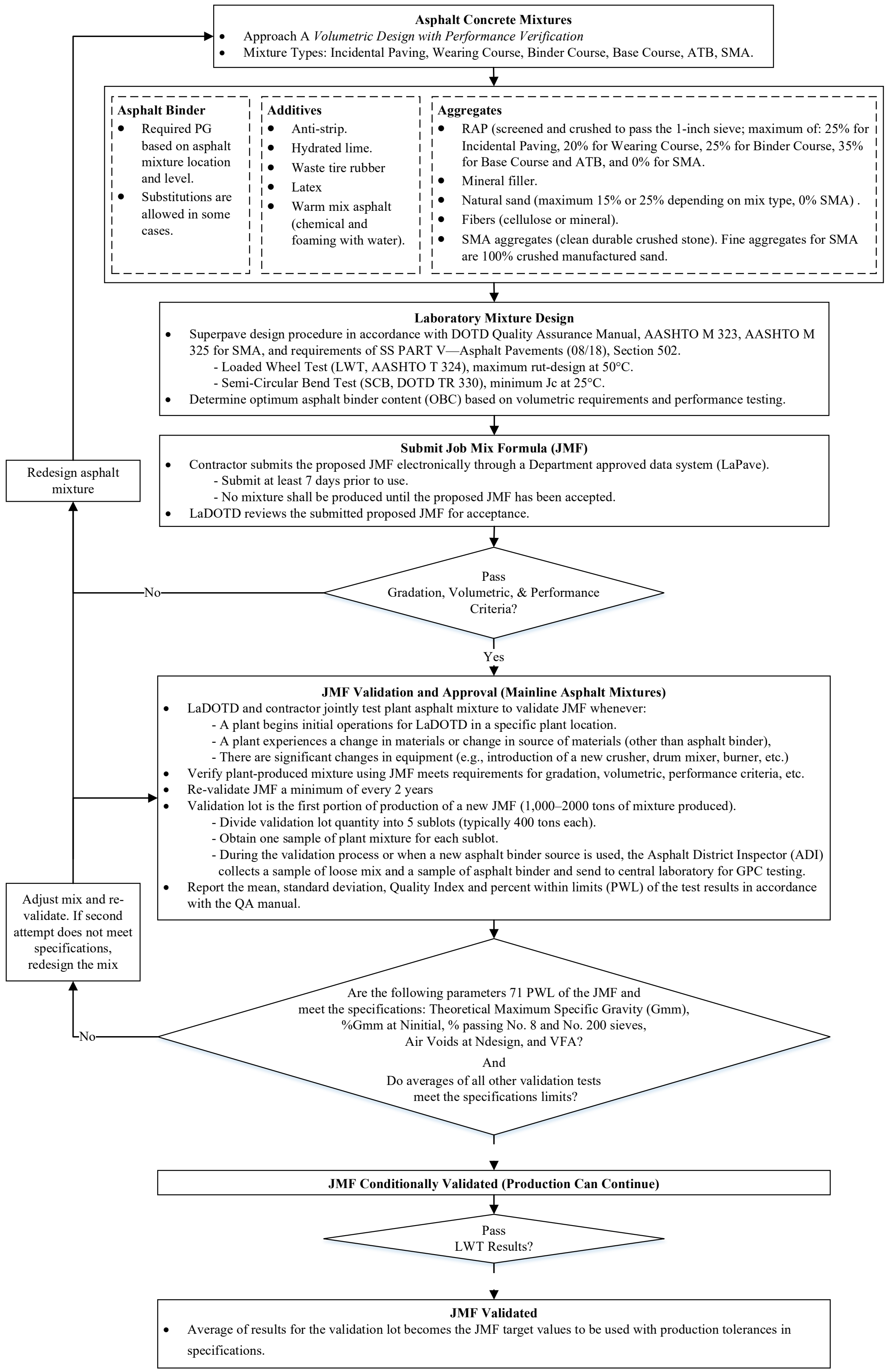

Figure 1. Chart. Overview of LaDOTD's BMD approach for asphalt concrete mixtures (Section 502—2018 amendments).

Table 3. Asphalt Binder Grade Requirements.

Mixture Type		Asphalt Binder PG Required	Substitutions Allowed	
			Lower Grade	Higher Grade
Thin Asphalt Concrete Applications	Dense Mix	PG 70-22	–	–
	Coarse Mix	PG 70-22m	–	–
	OGFC	PG 76-22m	–	–
Asphalt Concrete Mixtures	Mainline Wearing and Binder Course—Level 1	PG 70-22m	PG 67-22 with traffic volume < 3500 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 (required 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.

Table 4. Mix Design Volumetric Requirements.

Mixture Type		N_{design}	Asphalt Binder Content (%)	Design Air Voids (%)	VMA (Minimum %) Nominal Maximum Aggregate Size (NMAS) (mm)					Dust-to-Binder Ratio	Drain-down (%)[#]
					37.5	25	19	12.5	9.5		
Thin Asphalt Concrete Applica-tions	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%
Asphalt Concrete Mixtures	Incidental Paving	55	–	2.5–4.5*	–	–	–	13.5	–	0.6–1.6	–
	Wearing Course—Level 1	55	–	2.5–4.5*	–	–	–	13.5	–	0.6–1.6	–
	Wearing Course—Level 2	65	–	2.5–4.5*	–	–	12.5	13.5	–	0.6–1.6	–
	Binder Course—Level 1	55	–	2.5–4.5*	–	11.5	12.5	–	–	0.6–1.6	–
	Binder Course—Level 2	65	–	2.5–4.5*	–	11.5	12.5	–	–	0.6–1.6	–
	Base Course—Level 1	55	–	2.5–4.5*	10.5	11.5	–	–	–	0.6–1.6	–
	ATB—Level 1	30	≥ 3.0	2.5–4.5*	–	–	–	–	–	0.6–1.6	–
	SMA	65	≥ 6.0	2.5–4.5*	–	–	–	16.0	–	0.6–1.6	–
Asphalt Concrete Mixtures (< 1,000 ADT)	Incidental Paving	40	–	2.5–4.5*	–	–	–	14.0	15.0	–	–
	Wearing Course	40	–[$]	2.5–4.5*	–	–	–	14.0	15.0	–	–

–Not applicable.
[#]ASTM D6390.
*Design target voids at mid-point of void requirement. Full range allowed for OGFC.
[$]Voids filled with asphalt (VFA) requirement of 72–80%.

Table 5. Performance Test Requirements.

Mixture Type		LWT, maximum rut-design @ 50ºC*	SCB, Jc @ 25ºC (KJ/m^2)
Thin Asphalt Concrete Applications	Dense Mix	≤ 12 mm @ 12,000 passes	–
	Coarse Mix	≤ 12 mm @ 20,000 passes	–
	OGFC	≤ 12 mm @ 5,000 passes	–
Asphalt Concrete Mixtures	Incidental Paving	≤ 10 mm @ 10,000 passes	–
	Wearing Course—Level 1	≤ 10 mm @ 20,000 passes	≥ 0.5
	Wearing Course—Level 2	≤ 6 mm @ 10,000 passes	≥ 0.6
	Binder Course—Level 1	≤ 10 mm @ 20,000 passes	≥ 0.5
	Binder Course—Level 2	≤ 6 mm @ 20,000 passes	≥ 0.6
	Base Course—Level 1	≤ 12 mm @ 20,000 passes	–
	ATB—Level 1	≤ 10 mm @ 10,000 passes	–
	SMA	≤ 6 mm @ 20,000 passes	≥ 0.6
Asphalt Concrete Mixtures (< 1,000 ADT)	Incidental Paving	≤ 10 mm @ 10,000 passes	–
	Wearing Course	≤ 10 mm @ 15,000 passes	≥ 0.5

–Not applicable.
*Compact LWT specimens to the mid-point of design void requirement, OGFC to 18% air voids.

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}.
- Voids filled with asphalt (VFA).

The averages of all other validation tests, including SCB test results (i.e., Jc), shall meet the related specifications limits. The production can continue during conditional validation. The JMF is considered validated with passing LWT test 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 if 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.

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.

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 4 to table 6):

Table 6. Modifications to AASHTO Standard Volumetric Design Criteria.

Requirements	Mixture Type								
	Thin Asphalt Concrete Mixtures		Asphalt Concrete Mixtures					Asphalt Concrete Mixtures (< 1,000 ADT)	
	Dense Mix	Coarse Mix and OGFC	Inci-dental Paving	Wearing and Binder Courses	Base Course — Level 1	ATB—Level 1	SMA	Incidental Paving	Wearing Course
Number of Design Gyrations (N_{des})	↓	↓	↓	↓	↓	↓	↓	↓	↓
Density at N_{des}	↓	↓	↑	↑	↑	↑	↑	↓	↓
Density at Maximum Number of Gyrations (N_{max})	↔	↔	↔	↔	↔	↔	↔	↔	↔
Design Asphalt Binder Content	Min	Min	–	–	–	Min	Min	–	–
Voids in Mineral Aggregate (VMA)	–	–	↓	↓	↓	↓	↑	↔	↔
Voids Filled with Asphalt (VFA)	–	–	–	–	–	–	–	–	↑ LL
Dust-to-asphalt binder ratio	↑ UL	–	↑ UL	↑ UL	↑ UL	↑ UL	↑ UL	–	–
Natural Sands	Max	–	–	Max	Max	Max	Max	–	Max
Draindown (%)	–	Max	–	–	–	–	–	–	–
LWT Rut Depth at Specified Passes	Max	Max	Max	Max	Max	Max	Max	Max	Max
SCB, Jc	–	–	–	Min	–	–	Min	–	Min

–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.

- Specified 30 to 75 gyrations for design and acceptance of all asphalt mixtures.
- Specified a minimum asphalt binder content for thin asphalt concrete mixtures (Dense Mix. Coarse Mix, and OGFC), ATB Level 1, and SMA. In order to avoid bleeding of the asphalt mixture a draindown requirement (ASTM D6390) was also specified for Coarse Mix and OGFC.
- Increased target design air voids at N_{design} for thin asphalt concrete mixtures. On the other hand, reduced target design air voids by 0.5% for all asphalt concrete mixtures.
- Whenever specified, the VMA requirements were lower by 0.5% than the respective requirements in AASHTO M 323 for Superpave asphalt mixtures. Nonetheless, these VMA requirements are higher by 0.5% than what was specified prior to the 2016 standard specifications. This increase in VMA was introduced in the 2016 standard specifications to increase the durability of asphalt mixtures by allowing more asphalt binder into the mixture.
- Except for asphalt concrete mixture wearing courses on low volume roads (< 1,000 ADT), excluded the requirement for voids filled with asphalt (VFA) for all asphalt mixtures.
- Increased the upper limit of the dust-to-asphalt binder ratio requirement by 0.4% and excluded requirement for asphalt concrete mixtures on low volume roads (< 1,000 ADT).
- Increased the maximum allowable RAP by 5% for all mixtures relative to the maximum RAP percentage specified in the 2016 standard specifications.

SELECTION OF PERFORMANCE TESTS

Table 7 summarizes the performance tests currently used by LaDOTD for their BMDs of asphalt mixtures. LTRC is currently evaluating the feasibility of using a scaling factor to estimate SCB test results for long-term oven aged specimens based on testing of short-term aged conditioned specimens. Thus, allowing for the potential use of SCB test during production for acceptance.

LTRC has a long history of using the LWT (since early 2000) and SCB (since 2002) for forensic evaluation or as a research tool for screening of asphalt mixtures with well and poor rutting and cracking resistance potential, respectively. LaDOTD also relied on the fact that several SHAs have successfully used or implemented (e.g., 2004 TxDOT specifications) a version of the LWT to evaluate rutting potential and moisture susceptibility of their asphalt mixtures. Prior LTRC research studies also revealed the premises of the SCB test to predict the fracture resistance of asphalt mixtures. The effort to evaluate the combined use of LWT and SCB in asphalt mixture design was initiated in 2011. The LWT and SCB tests have been implemented in the standard specifications since 2016.

Table 7. Summary of Performance Tests Considered by LaDOTD for BMD.

Elements	Stability/Rutting	Durability/Cracking	Moisture Damage/Stripping
Test Name	Loaded wheel test (LWT)	Semi-circular bend (SCB) test	Loaded wheel test (LWT)
Test Method	AASHTO T 324	ASTM D8044	AASHTO T 324
Test Criteria	Refer to table 5.	Refer to table 5.	Refer to table 5.
Test Implemented in Asphalt Mixture Design	Yes.	Yes.	Yes.
Aging Protocol	Lab-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C). Plant-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C).	Lab-produced mixtures: Long-term conditioning procedure in accordance with AASHTO R 30 (5 days at 85°C). Plant-produced mixtures: Long-term conditioning procedure in accordance with AASHTO R 30 (5 days at 85°C).	Lab-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C). Plant-produced mixtures: Short-term conditioning procedure for mechanical properties in accordance with AASHTO R 30 (4 hours at 135°C).
Notes/Comments	–	The SCB is being evaluated 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.	–

–Not applicable, not specified, or no comments.

While LWT is used to assure no early rutting failure of asphalt pavement, the SCB was first introduced to control the cracking performance of asphalt mixtures during the mix design process in the laboratory as LaDOTD started to observe premature cracking failures. Asphalt mixtures in LaDOTD were stiff and dry, which impacted their cracking resistance and flexibility.

The top three factors for LaDOTD in selecting a performance test are: field validation, material sensitivity, and repeatability. Field validation and correlation of performance test results with measured field pavement performance data is the basis for any 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). 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 quality control 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.

Table 8 summarizes a comparison between the LWT and SCB tests in terms of their simplicity. In particular, the SCB test was selected for implementation in BMD approach because:

- It is an intermediate temperature test for intermediate temperature fracture that addresses the observed type of cracking in LA asphalt pavements.
- It can be conducted using 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 coefficient of variation (COV) less than 15%.

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. 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.

The LaDOTD central materials laboratory in Baton Rouge does not own an Asphalt Mixture Performance Tester (AMPT). LTRC owns two AMPTs that have been primarily used to conduct dynamic modulus and flow number (AASHTO T 378) tests on asphalt mixtures from around the state for pavement design purposes (AASHTOWare® Pavement ME). The AMPTs have also been used in research projects to conduct direct tension cyclic fatigue test, overlay test (OT), etc.

Table 8. Comparison Between the LWT and SCB Tests.

Factors	LWT (AASHTO T 324)	SCB (ASTM D8044)
Time for preparing samples	• Compact, cut, and perform volumetric measurements. • 1 day for a set of 4 test specimens.	• Compact, cut, notch, and perform volumetric measurements. • 1 day for a set of 12 test specimens.
Testing specimens	• 1 day for a set (2 samples = 4 test specimens).	• 1–2 hours for a set (12 test specimens).
Analyzing data	• Spreadsheet: 30 minutes.	• Spreadsheet with cut/paste: 15 minutes.
Technician training requirements	• Minimal. • Several laboratories (State DOTs, Academia, Consultants)	• Minimal. • Several laboratories (State DOTs, Academia, Consultants)

PERFORMANCE TESTS DEVELOPMENT TO IMPLEMENTATION

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

Step 1. Draft test method and prototype equipment.

Having standard test procedures available supported efficient implementation of performance tests for asphalt mixtures. LaDOTD has established and used its own test method for SCB (DOTD TR 330) since 2014, before the ASTM D8044 test method was available. In fact, the ASTM D8044 test method originated form the DOTD TR 330 test procedure.

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

The sensitivity of 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 LaDOTD. 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. LaDOTD funded several research studies to evaluate the sensitivity of performance tests to material properties using typical asphalt mixtures from Louisiana (LA).

The studies evaluated the effect of several factors such as the asphalt 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.

In 2019, LaDOTD led the pooled fund project TPF-5(294) *Design and Analysis Procedures for Asphalt Mixtures Containing High-RAP Contents and/or RAS*. The results from this study aimed at providing guidance to SHAs in the selection of a fatigue/fracture performance test to incorporate during asphalt mixture design containing high-RAP and/or RAS materials.

Typically two field projects from each participating SHA were included, with each project comprising a conventional asphalt mixture and an asphalt mixture containing high RAP and/or RAS. The asphalt mixtures from the FHWA Accelerated Load Facility (ALF) experiment (10 test lanes) were also included. All mixtures from SHAs were evaluated for SCB, OT, energy ratio, flexural beam fatigue, and direct tension cyclic fatigue. Overall a good correlation was observed between the SCB Jc 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 Jc 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 Jc-based model. Overall the findings from the pooled fund study provided LaDOTD with additional confidence with the SCB test as part of the BMD approach.

Step 3. Preliminary field performance relationship.

LaDOTD development of the initial performance test criteria was undertaken during the development of a framework for the implementation of PBS for Louisiana (LTRC Project No. 10-4B). 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. LWT 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 LWT rut depth. On the other hand, the 20-year projected combined cracking indices (alligator cracking index—ACI, and random cracking index—RCI) were the field cracking performance indicators related to the SCB Jc. 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 (LA-PMS).

Based on the comparison analyses between the field and laboratory measured performance indicators, initial performance test criteria were established for the LWT measured rut depths for Level 2 and Level 1 asphalt mixtures in LA. Similarly, the minimum SCB Jc values of 0.6 and 0.5 kJ/m^2 were established for Level 2 and Level 1 asphalt mixtures to avoid crack related problems, respectively. Both, the LWT 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 PBS was also proposed while acknowledging the need to collect more field and laboratory performance data to validate the initial performance test criteria.

Step 4. Ruggedness experiment.

LaDODT did not conduct or participate in any formal ruggedness testing yet for LWT. LTRC recently completed the experimental testing for a ruggedness study for SCB (ASTM D8044) following ASTM E1169. The study evaluated several factors including specimen thickness, notch depth, specimen height, air voids, loading rate, test temperature, etc. The data have been analyzed and a final report summarizing the findings from this study will be published in the near future.

The NCHRP project 09-57A Ruggedness of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures (https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4471) recently completed a ruggedness study for the SCB (ASTM D8044). The following seven factors were considered for the SCB test in the ruggedness experiments: specimen thickness, notch depth, notch location, specimen height, air voids, loading rate, and test temperature. Based on this study, none of the seven evaluated factors were significant, thus warranting some revisions to the test method for relaxing certain specific requirements of these factors.

In a separate study, the robustness of the SCB test was studied using a discrete element method (DEM) approach to analyze the fracture behavior of SCB samples. DEM was used to develop a model for the SCB test that was used to study the effect of seven parameters on test results: notch location, notch depth (low, intermediate and high), air voids, loading rate, and span length. The DEM modeling showed that the parameters with most positive effect were intermediate notch depth and notch location, while those with the most negative effect were loading rates and air voids.

Step 5. Commercial equipment specification and pooled fund purchasing.

In 2015, LTRC completed the NCHRP Project 20-07/Task 361 Hamburg Wheel-Track Test Equipment Requirements and Improvements to ASHTO T 324. The study evaluated the capability of the LWT 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 LWT equipment. The main findings were related to the wheel position waveform, temperature control system, deformation measurements, and data collection and reporting.

The LaDOTD central materials laboratory and each of the nine DOTD districts have currently an LWT equipment that were all purchased during the pilot study phase of the implementation. LTRC currently has two LWT equipment, and seven devices are owned by contractors around the state.

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 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 mixture designs in LA are generally conducted by the contractor supplying the asphalt mixture.

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

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

None of the performance tests have information regarding the precision and bias of the test method. This creates a potential issue if two separate laboratories achieve different test results for the same asphalt mixture. Historically, a COV of less than 20% has been observed with the LWT and SCB test results from the same laboratory. Early on in the process the variability of the SCB test results was high (COV ~30%), which triggered a thorough investigation. This high variability in the test results was related to specimen fabrication. Thus, improvements were made and a quality control form for specimen fabrication was developed and shared with technicians for employment.

LaDOTD plans on using the test results of the proficiency testing program to establish the variability within each laboratory and between laboratories for the LWT. 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.

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

LaDOTD validation of the initial performance test criteria was based on historical database of LWT 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. In total, SCB and LWT test results were available for 51 asphalt mixtures. Based on the results of the analysis (LTRC Project No. 11-3B), the following findings and conclusions were made:

- LWT:
  - 90% of evaluated asphalt mixtures passed the proposed initial criteria specified for acceptable rutting resistance. The criteria for unmodified and polymer-modified asphalt 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 asphalt mixtures in comparison to the unmodified asphalt mixtures.
- SCB:
  - 38%, 68%, 91%, and 20% 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 LWT and SCB parameters.

- 64% 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 asphalt 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 Jc. Thus, requiring further investigation before implementation of the use of field cores for quality acceptance practices.

The asphalt mixtures from the FHWA ALF experiment also provided additional robust validation of the SCB test. The SCB test results were also compared and validated against the flexural beam fatigue and the direct tension cyclic fatigue tests.

Further validation and refinements to the performance test criteria are anticipated with additional field pavement performance data and related laboratory performance test results. This can result in a revised specification for design, quality assurance, and performance test thresholds values.

Step 8. Training and certification.

Training technicians on the procedures and analysis of test results is necessary. LaDOTD offered an SCB Test Training Workshop on April 16, 2015 to contractors, LaDOTD, and consultants. The training workshop was conducted 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 a training video of over 13 minutes long 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 extremely helpful for the attendees and other involved personnel in the implementation process of the SCB test.

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

LaDOTD requires technicians to be certified and/or qualified for performing design, sampling, testing, and inspections. Contractor's technicians should be qualified to sample and test, certified to design, produce, control, and adjust their operations. When producing asphalt mixture, the contractor should employ a Certified or Qualified Asphalt Concrete Plant Technician in accordance with specification requirements. The Technician must be present at the plant whenever plant operations are supplying materials to a LaDOTD project. Daily plant operations will not commence unless a Certified Technician is present. Technicians for both the contractor and LaDOTD should be qualified and/or certified for testing according to the levels listed below for Asphalt Plant Technician:

- Qualified Aggregate Tester.
- Qualified Asphalt Concrete Plant Level I.
- Certified Asphalt Concrete Plant Level II.
- Certified Asphalt Concrete Plant Level III.

LWT and SCB performance testing are part of the Asphalt Concrete Plant Level II and Level III certifications.

LaDOTD requires laboratories to be accredited by AASHTO re:source, CMEC, or other 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 to participate in a statewide proficiency testing program. Under this program, technicians will be required to fabricate and test specimens for Gmm, volumetrics, and LWT. The reported test results are analyzed to insure that technicians are properly performing the tests in accordance with applicable standards.

Step 9. Implementation into engineering practice.

LaDOTD has been investing significantly in research over the years to support the implementation of performance tests and BMD for design and acceptance. The following summarizes the major steps that were undertaken to implement BMD into engineering practice:

- 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. Throughout the process, LaDOTD kept the industry involved 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 LWT and SCB specimens (samples were initially compacted to different heights).

IMPLEMENTATION OF PERFORMANCE TESTS ON PROJECTS

LaDOTD has been leading and investing significantly in the process to develop and implement a BMD for its standard asphalt mixtures. This is stems from LaDOTD's immediate need to address premature failure of asphalt mixtures with innovative and recycling materials.

Once a plant is producing an acceptable JMF, the JMF production need to be kept within the specified tolerances. For plant quality control, a sublot 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. A sample of plant-produced asphalt mixture is obtained and tested once every sublot in accordance with table 9.

Table 9. Production Testing Frequency for Asphalt Concrete Mixtures (Section 502).

	Loose Asphalt Mixture[1]			Compacted Specimens		
Entity	**Gmm and Asphalt Binder Content[2]**	**Gradation and Coarse Aggregate Angularity**	**Tempera-ture and Moisture Content[3]**	**%Gmm at $N_{initial}$, Air Voids, VMA, and VFA[4]**	**%Gmm at N_{max}**	**LWT**
Contractor	1 per sublot	1 per sublot	1 per sublot	1 per sublot	1 per 5 sublots	–
LaDOTD	Randomly	Randomly	–	Randomly	–	Every 20,000 tons

–Not applicable.
[1]Loose mixture aged for 1 hour (2 hours for warm-mix asphalt) in accordance with AASHTO R 30 prior to testing.
[2]Sublot Gmm is used in the determination of plant air voids and in-place density of the corresponding pavement sublot.
[3]Moisture content measured daily on the cold feed aggregates and on the final mixture.
[4]Properties measured at N_{design}.

The rolling five test results average and standard deviation for aggregate gradation, asphalt binder content, air voids, VFA, VMA, and Gmm are determined. Corrective action or cease of production is taken when the latest rolling five test results show air voids or Gmm fall below 71 PWL; or average VMA, VFA, asphalt binder content, or percent passing No. 8 or No. 200 sieve is outside of specification limits. The full range of gradation mixture tolerances applied to the validated JMF will be allowed even if they fall outside the control points. Termination or re-validation of the JMF may be required when the average of the quality control data indicates non-compliance with the specified limits or tolerances.

During production, the DOTD's certified asphalt plant inspector will randomly visit and inspect asphalt plants, sample and test material, and review documentation to ensure conformance to specification requirements. Table 9 summarizes the samples taken by the asphalt plant inspector and that may be tested for verification. As shown in table 9, the asphalt mixture is tested for rutting and moisture susceptibility using LWT every 20,000 tons of production per JMF (this is increased to every 10,000 tons for Section 501 asphalt mixtures). The LWT 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.

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 mixture design requirements, sampling, and testing logistics; and 2) to validate the established threshold criteria for LWT and SCB test parameters. The pilot projects also facilitated the early buy-in form the industry before full implementation into the standard specifications in 2016.

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 field projects thus far, 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%) were the right step towards a successful implementation of LWT 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.
- The initial challenges with implementing the LWT 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.
- An increase in asphalt binder content by 0.2–0.3% was generally observed. Nonetheless, this increase was mainly driven by the decrease in N_{design} and the increase of VMA requirements. An increase in asphalt binder content to meet the SCB Jc was not always necessary. There was specifically a need to increase the effective asphalt binder content of the mixture by restructuring the aggregate gradation and bin percentages. Meeting the LWT requirement was generally not an issue.
- 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 Jc-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.
- 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, weight

bridges, etc. have become more critical for the production of an asphalt mixture that is 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 asphalt binder content of mixtures.

OVERALL 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. Furthermore, the traditional volumetric-based mixture 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.

Using collected field pavement performance, LTRC is working on quantifying and documenting the cost-benefit of the BMD specifications in comparison with standard asphalt mixture 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 should lead to increase in asphalt pavement service life.

LaDOTD believes that the implementation of BMD should result in cost savings by providing contractors with more flexibility during the asphalt mixture 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 LWT and SCB, with which LaDOTD has had a long history of using them. 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 Jc results of short-term aged specimens.
- Establish and/or implement necessary precision and bias statements for LWT and SCB performance tests.
- Document the cost-benefit of the BMD specifications in comparison with standard asphalt mixture 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.

POSITIVE PRACTICES, LESSONS LEARNED, AND CHALLENGES

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

Positive Practices

- The motivations for implementation of BMD in LA 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 asphalt 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 quality acceptance practice that is mainly based on asphalt mixture volumetric properties.
- Partnering with and collaboration between LaDOTD, LTRC, industry, and academia is integral for a successful and smooth implementation of performance tests as part of asphalt mixture design and acceptance. This involves good communication and continuous dialogue with the industry, knowledge transfer, and necessary education and training.
    - Internally, there is a strong commitment, support, and contribution to the development effort of BMD.
    - Externally, having strong and established relationship with academia (Louisiana State University) have been instrumental for carrying the various steps involved in the development of BMD. Having an established program through the state to support critical and pressing research was key in the development and implementation of performance tests and BMD.
    - Externally, having industry partners that participated in 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.
- LaDOTD has been going through a rigorous process for implementing BMD into engineering practice including: building-up experience and establishing a large database of performance test results; developing pilot specifications for BMD; investing and carrying out a pilot program with field pavement trials; acquiring new equipment for performance testing; making practical adjustments to the test methods; assuring industry buy-in for the BMD approach; and providing necessary training and support to the industry on test methods and data analysis.
- Having an electronic online system such as LaPave to submit JMFs and related documentations facilitated the review and approval process by LaDOTD. It also provided an easy access to extract and retrieve JMFs and other related information on projects in an efficient manner.
    - All JMFs are re-validated a minimum of every 2 years. The JMF is only approved once at the state level.
    - A JMF is for a mainline asphalt mixture is validated whenever an asphalt plant begins initial operations in a specific plant location; whenever a plant experiences a change in materials or change in source of materials (other than asphalt binder source); or when there are significant changes in equipment.
    - When a new asphalt binder source is used, a sample of asphalt binder is collected and sent to the central materials laboratory for GPC testing.
- Having test procedures available supported efficient implementation of performance tests for asphalt mixtures (Step 1).
    - Continuously improve and update test procedures and analysis methodologies to improve test analysis and repeatability.
    - LaDOTD support of the research effort to modify the SCB test to be practical for incorporation into asphalt mixture designs to complement the LWT.
- LaDOTD funded several research studies to evaluate the sensitivity of performance tests to material properties using asphalt mixtures typically used in LA (Step 2). This allowed LaDOTD to build a large database of performance test results over the years.
    - Establishing a database of test results helps in understanding the performance of typical asphalt mixtures and in establishing initial performance test criteria.
- The top factors in selecting LWT and SCB were (Steps 3 and 7):
    - LaDOTD has a long history of using the LWT (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.
    - The SCB test at intermediate temperature was first introduced to control the cracking performance of asphalt mixtures since LaDOTD asphalt mixtures were known to be stiff and dry.
    - The field validation and correlation of performance test results with measured field pavement performance data, material sensitivity, and repeatability were a key consideration in the development and implementation of test criteria into the specifications.
    - The duration needed for sample preparation, equipment cost, and training needs were additional key considerations in the development and implementation of test

criteria into the 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.
    - Both the LWT and SCB tests are relatively simple to conduct and can be performed using gyratory compacted specimens or field core specimens.
    - The SCB test is fundamentally derived from fracture mechanics principles and is not simply an index test (go/no-go or pass/fail).
    - 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 FHWA ALF results provided LaDOTD with an additional robust validation of the SCB test parameter.
    - SCB test results were also compared and validated against other fundamental tests such the flexural beam fatigue and the direct tension cyclic fatigue tests.
- Requiring all laboratories to be accredited and technicians to participate in the proficiency testing program of LWT assured the proper conduct of performance tests. The test results will be used determine the single and multiple operator variability (Step 6).
- Having certification and/or qualification programs in-place for performing design, sampling, testing, and inspections that are supported by both LaDOTD and industry facilitated the training of technicians on performance tests (Step 8).
    - LWT and SCB performance testing are part of the Asphalt Concrete Plant Level II and Level III certifications.
- Keys to implementation (Step 9) included:
    - Having multiple pilot projects across the state so that contractors can have an opportunity to gain experience and become familiar and comfortable with the process before full implementation.
    - Pilot projects helped to work out asphalt mixture design requirements, sampling, and testing logistics; and to validate the established threshold criteria for LWT and SCB test parameters. The pilot projects facilitated the early buy-in form the industry before full implementation into the standard specifications.
    - Consider a phased in approach for the implementation of BMD with initially no ties to pay factors.
    - Changes to the volumetric design criteria of asphalt mixtures (e.g., reduction in N_{design}, increase in VMA) preceded the implementation of performance tests. This helped and guided contractors in their effort to meet the applicable performance test criteria.
    - LaDOTD help and support to contractors with performance tests (training on equipment and test result calculations) were essential to make sure that tests are being properly conducted in the contractor laboratory.
- There have been benefits:
    - Asphalt mixtures designed using the BMD approach were in general easier to compact in the field and to reach target in-place density

  - The BMD allowed contractors to use innovative and recycled materials (i.e., RAP) in order to produce asphalt mixtures that are in compliance with LaDOTD specifications.

Lessons Learned

During the construction of the test projects, several lessons were learned related to the laboratory testing and plant operation processes.

- Laboratory testing processes:
  - 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.
  - The asphalt binder performance grade and modifications were found to influence the performance test results of asphalt mixtures.
  - Increasing asphalt binder content by 0.2–0.3% improved the SCB test results without jeopardizing LWT results. Though, an increase in asphalt binder content to meet the SCB Jc was not always necessary. There was specifically a need to increase the effective asphalt binder content of the mixture by restructuring the aggregate gradation and bin percentages.
  - The variability of the SCB test results was high (COV ~30%), which required a thorough investigation. This high variability in the test results was related to specimen fabrication. Thus, improvements were made to specimen fabrication and a quality control form was developed to be utilized by technicians.
  - The BMD for asphalt mixtures allowed the use of higher RAP contents without jeopardizing the cracking performance of asphalt mixtures.
- Plant operation processes:
  - Validation of plant-produced asphalt mixtures was a critical and important step of the process in order to make sure that the asphalt mixture is in compliance during production.

Challenges

- The long-term oven aging of 5 days for SCB specimens impacts the time needed to approve and accept an asphalt mixture design and limit the use of the test for acceptance during production.
- 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.
- Performance test methods lack precision and bias, thus creating a potential issue if two separate laboratories achieve different test results for the same asphalt mixture.
- Contractor faced some challenges initially with equipment and analysis of performance test results. Contractor sought help from LaDOTD on how to properly conduct and analyze raw test data.

- The need for funding and resources to design and complete ruggedness experiments for performance tests.
- Comparison of plant-produced specimens to core specimens revealed a potential effect for specimen type on the SCB Jc. Further investigation is needed before implementation of the use of field cores for quality acceptance practices.

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.

RESEARCH AND DEPLOYMENT OPPORTUNITIES

LaDOTD suggests the following research and deployment topics:

- Optimization of the laboratory aging conditions for asphalt mixtures to accelerate testing.
- Impact of sample fabrication on performance test results.
- Examination and evaluation of cyclic SCB test for determining the asphalt mixture resistance to fatigue cracking under repeated loading.
- Training materials and hands-on workshops on testing, analysis, and interpretation of performance test results including the influence of changes in asphalt mixture composition and components during design or production on performance.

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