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Balanced Mix Design—A 1-Year Reality Check on Quality Control Testing and State DOT Adoption

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13. Abstract
Balanced Mix Design (BMD) represents a major advancement in asphalt pavement engineering. As a performance-driven framework, BMD integrates mix design, structural design, quality assurance/quality control (QA/QC), and performance-related specifications (PRS) to promote durable and sustainable pavements and innovations. This synthesis documents the evolution and current state of BMD implementation across the United States, with particular emphasis on SASHTO member states. It is based on an extensive literature review, including a comprehensive compilation of national and state research studies, first-round survey responses from 36 state Departments of Transportation (DOTs), and second-round feedback from eight SASHTO DOTs. The analysis summarizes progress and variability across performance testing, aging protocols, QA/QC integration, and specification development, and catalogs more than 170 state-based BMD studies. Key recommendations include establishing standardized testing protocols, adopting variability-informed QA/QC criteria, identifying practical long-term aging surrogates, and implementing stepwise strategies for volumetric relaxation. Collectively, these findings provide a national and regional

perspective on BMD implementation, challenges, and emerging best practices, supporting SASHTO leadership, member agencies, and other stakeholders in advancing toward a standardized performance-based asphalt mixture design framework.

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Balanced Mix Design—A 1-Year Reality Check on Quality Control Testing and State DOT Adoption

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March 2026

Executive Summary

Balanced Mix Design (BMD) has emerged as one of the most prominent, actively discussed, and extensively investigated advancements in the asphalt pavement industry. By shifting the emphasis from solely volumetric-based approaches to performance-based design, BMD addresses the fundamental limitations of traditional volumetric-based design. These limitations become increasingly consequential as agencies expand the use of recycled and modified materials. Mixtures incorporating high proportions of reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), polymers, ground tire rubber (GTR), and plastics may exhibit performance sensitivities that are not consistently captured by volumetric parameters alone, particularly under diverse climatic conditions, traffic demands, and construction practices. In response to these challenges, the Federal Highway Administration's (FHWA) Performance Engineered Pavements (PEP) initiative has positioned BMD as a core component of a performance-based framework that integrates mix design, performance-related specifications (PRS), quality assurance (QA), and ultimately field performance outcomes.

This synthesis evaluates the development, evolution, and implementation of BMD research and practice across the United States, with particular emphasis on the member states of the Southeastern Association of State Highway and Transportation Officials (SASHTO). By documenting the growing portfolio of state-led research studies, pilot programs, and field validation efforts, the synthesis supports the refinement of BMD procedures and facilitates broader, more consistent adoption. This report highlights both the progress made and the persistent needs in: standardizing performance test protocols; establishing practical short- and long-term aging/conditioning methods for mix design and QA/QC that remain representative of field conditions; defining realistic, climate- and traffic-sensitive performance thresholds; developing variability-informed QA/QC strategies and acceptance frameworks; and building integrated data systems that enable cross-project learning and cross-state benchmarking. Collectively, the synthesis provides actionable insights and recommendations to assist Departments of Transportation (DOTs) and industry stakeholders in transitioning to performance-driven BMD implementation, supported by a coherent, implementable QA/QC framework.

The primary objectives of this synthesis are summarized as follows:

- Conduct a comprehensive review of relevant literature, national guidance documents, and performance testing standards that inform BMD practice.

- Assess performance testing and conditioning methods for both short- and long-term aging, documenting current approaches, practical constraints, and knowledge gaps.
- Document state implementation efforts and summarize variations in current practices, acceptance approaches, and specification frameworks.
- Catalogue state-sponsored research, pilot trials, and field validation projects, developing a consolidated summary to support cross-state benchmarking and identification of commonalities and discrepancies.
- Design, distribute, and analyze two rounds of surveys targeting state DOT personnel and stakeholders to capture implementation strategies, barriers, and research/practice needs.

Although the synthesis is centered on the SASHTO region, it is informed by a national perspective. To date, the effort has catalogued more than 170 research projects, pilot initiatives, and technical publications, providing a robust basis for assessing BMD maturity across the nation and within the Southeast. A key component of the study is a two-round survey distributed to state DOTs, designed to capture implementation strategies, challenges, and gaps. The first round captured broad national implementation status and concerns across 36 states, while the second round focused on more detailed input from SASHTO member agencies in eight states. The panel discussion on BMD implementation in southeastern U.S. states during the 2025 SEAUPG Annual Meeting & Exhibits is also summarized. Analysis of the survey feedback clarifies practical challenges and unresolved issues related to performance testing selection and variability, sample conditioning and aging protocols, data management and integration, and the alignment of BMD outcomes with QA/QC and acceptance practices. A summary of the survey feedback is listed below:

- Performance testing is the dominant focus within current BMD efforts. Cracking tests (e.g., IDEAL-CT, I-FIT, SCB, DCT) and rutting tests (e.g., HWTT, APA, IDEAL-RT) form the core of practice and have driven substantial progress in test selection and threshold development. However, repeated state-by-state investigations could create redundancy and contribute to inconsistent, locally defined thresholds, while surface functional metrics such as friction and texture remain comparatively underrepresented.
- Variability and sensitivity studies have improved understanding of precision, repeatability, and production variability, yet these findings have not been consistently translated into enforceable QA/QC acceptance criteria.
- Aging protocols continue to evolve, but a field-calibrated long-term aging (LTA) approach that reflects climate and mix-type effects remains a critical need. Time-feasible

LTA surrogates or predictive approaches could offer a promising pathway to address long turnaround times, particularly for QA/QC.

- Overall, many agencies have progressed beyond pilot work toward early implementation, with advancing efforts in framework development, QA/QC integration, and field validation. To achieve durable, consistent BMD practice, conceptual frameworks must now be converted into implementable specifications. Emerging interests include RAP/RAS integration, modifiers and additives, and structured volumetric relaxation strategies.

The collective evidence supports cross-state learning and yields targeted recommendations to reduce implementation uncertainty, improve the comparability of results, and accelerate the transition toward a standardized, performance-based asphalt mixture design framework:

- Establish regional benchmarking (i.e., reference distributions) for key tests (e.g., IDEAL-CT, HWTT, IDEAL-RT, etc.) and harmonize protocols to improve threshold consistency and reduce duplication.
- Translate precision and reproducibility findings into variability-aware acceptance criteria, risk-balanced pay factors, and clear QA/QC testing frequencies.
- Develop a practical, standardized LTA matrix linking laboratory conditioning to field aging, including QA-feasible surrogates/predictions across climates and mix types.
- Implement end-to-end mechanistic-empirical (ME) or FlexPAVE demonstration projects that connect mixture performance indices to structural design parameters and field performance (e.g., PMS feedback).
- Integrate friction and texture metrics, if practical, into BMD frameworks for surface and OGFC mixtures to better reflect safety and functional performance.

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Table of Contents

List of Tables

List of Figures

Introduction

Balanced Mix Design (BMD) is defined as “asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress, taking into consideration factors such as mix aging, traffic, climate, and the location within the pavement structure” [1]. This definition is also endorsed in the Glossary of Terms for Balanced Design of Asphalt Mixtures [2]. Current volumetric-based mix design methods (e.g., Hveem, Marshall, and Superpave) do not sufficiently capture pavement performance under varying climate conditions and traffic loads [3]. As a result, mixtures that satisfy volumetric property specifications frequently exhibit premature distress, such as cracking and rutting, when applied in actual pavement construction and in-service conditions. The growing incorporation of modified or recycled materials, including polymers, ground tire rubber, plastics, recycling agents, reclaimed asphalt pavement (RAP), and reclaimed asphalt shingles (RAS), has further exacerbated these performance issues.

For this reason, the implementation of volumetric-based mix design systems has often been associated with durability issues in the field. Many state highway agencies are actively investigating the feasibility of adopting BMD to develop and construct long-term asphalt pavements tailored to local conditions. These efforts are being carried out through a variety of BMD-focused research initiatives across the United States. In 2019, the U.S. Federal Highway Administration (FHWA) introduced the Performance Engineered Pavements (PEP) vision [4] [5], which emphasizes enhancing long-term pavement performance through the integration of structural pavement design, Performance Engineered Mixture Design (PEMD), Quality Assurance (QA), and performance-based acceptance. A central component of this initiative for the asphalt aspect is the adoption of Balanced Mix Design (BMD) and Performance Related Specifications (PRS).

Based on the summary of current BMD implementation, a practical, widely accepted framework for selecting appropriate combinations of performance tests and procedures for various applications in BMD remains an active area of trial, pilot, and research studies. Thus, refining the BMD process and developing a comprehensive synthesis encompassing design, production, and placement is essential. This synthesis study aims to empower highway agencies and organizations to effectively evaluate and select balanced asphalt mixtures for pavement structures, while also providing clearer guidance for states' objectives of BMD-related research projects. Current specifications on performance sensitivity and thresholds from BMD-related research rely heavily on limited laboratory data, often confined to a single lab or state. This narrow scope makes it difficult to generalize findings to other mixtures or regions, leading to potential overfitting to local conditions.

The challenge also comes in implementing such performance tests on the plant-produced mixtures during the BMD quality assurance and quality control (QA/QC) workflow in a timely, production-feasible manner. Rutting resistance is primarily assessed during the early life of asphalt pavement, shortly after production and construction. Therefore, rutting tests should be conducted promptly using field cores, plant-produced specimens, or lab-compacted mixtures (e.g., using the Superpave Gyratory Compactor). This allows the test to be effectively integrated into the QA/QC process due to its relatively quick turnaround (i.e., shorter aging). Cracking resistance should be evaluated based on long-term aging (LTA) simulations at a certain temperature. Existing protocols (e.g., AASHTO R 30 [6], NCHRP 09-54 [7]) are adequate for mix design. However, applying LTA in the QA of plant-produced mixtures remains a challenge due to time constraints.

In the digital era, leveraging large datasets is transforming decision-making across disciplines. For BMD implementation research, analyzing large-scale datasets offers a stronger foundation for statistical analysis, yielding more accurate and reliable insights. Although a significant volume of BMD data has been generated by various state DOTs and agencies, it remains underutilized due to a lack of integration and comprehensive analysis. Unlocking the potential of this data through aggregation and systematic evaluation will significantly enhance research outcomes and support broader BMD adoption. Therefore, a comprehensive synthesis is needed to compile recent literature findings, assess current DOT practices, and evaluate completed or ongoing BMD research. This synthesis will identify discrepancies impacting regional implementation, analyze how individual states have applied project results and recommendations, and highlight common findings, conclusions, and recommendations across studies. Additionally, it will provide guidance on the applicability of research outcomes to other southeastern U.S. states and propose further research to support more effective implementation.

Objective

The objectives of this study are summarized as follows:

- Perform a literature review to identify ongoing or completed research on BMD procedures.
- Review BMD implementation and research projects in SASHTO states in the southeastern United States region on targeted synthesis topics.
- Conduct a two-round survey based on current BMD practices. The second-round survey is designed based on the outcomes of the first-round survey feedback.
- Based on the feedback of the surveys distributed to state agencies, analyze commonalities in project scopes and methodologies of BMD implementation within the southeastern United States region.
- Identify differences impacting implementation and highlight discrepancies that may affect regional implementation and practice.
- Review implementation status and assess how individual states have implemented project results and recommendations.
- Analyze project results and recommendations: identify common findings, conclusions, and recommendations across studies.
- Identify further research needs, if necessary, to support broader implementation.

Literature Review

History and Current Developments of Balanced Mix Design

The concept of Balanced Mix Design (BMD) originates from the Marshall and Hveem mix design methods, both of which aimed to balance mixture stability and durability [8]. The Superpave mix design system accounts for the effects of mixture properties and proportions on potential distress. Specifically, the Level II and Level III procedures within Superpave were designed as performance-based approaches, incorporating both volumetric analysis and laboratory performance testing, including the Superpave Shear Test and the Indirect Tensile Strength (IDT) Test [9]. However, due to practical constraints, such as test complexity, duration, and lack of field validation, these performance tests were never fully adopted in practice. Consequently, only the volumetric design aspect of Superpave was widely implemented across the U.S. The absence of performance testing has contributed to the adoption of suboptimal mix designs and premature distress, such as cracking and rutting, in asphalt pavements.

In response, researchers began integrating AASHTO-standardized performance tests into mixture design processes to better assess rutting resistance, cracking resistance, and moisture susceptibility. Field observations also revealed that many asphalt mixtures failed due to a single dominant distress mode, such as fatigue cracking or permanent deformation, indicating that the designs lacked a balanced resistance profile across multiple failure mechanisms.

Initially proposed in 2007 [8] to balance rutting and cracking, the BMD concept has since evolved to encompass other distresses and broader national implementation [10] [11]. In 2015, an Expert Task Group initiated a BMD Task Force to develop practical frameworks for implementation. AASHTO comprehensively included standard practice and performance testing requirements to guide the BMD in Balanced Design of Asphalt Mixtures [12] and Balanced Mix Design [13], respectively. These documents outline four BMD approaches [14]:

- Approach A: Volumetric design with performance verification
- Approach B: Volumetric design with performance optimization
- Approach C: Performance-modified volumetric design
- Approach D: Performance-based design

Figure 1. Graphical illustration of BMD approaches [14]:
(a) Approach A, (b) Approach B, (c) Approach C, and (d) Approach D

(a) (b)

(c) (d)

Figure 1 illustrates the flow chart of the design process for four BMD approaches. AASHTO MP 46 [13] outlines standardized performance tests for evaluating both rutting and cracking, providing at least one recommended test for each type of distress that highway agencies can adopt. Specifically, the specification includes eight tests for rutting assessment and 14 tests for cracking, including ten for intermediate-temperature cracking and four for low-temperature cracking.

In April 2025, the Balanced Mix Design (BMD) Implementation Working Group (IWG) presented a new standard of practice to AASHTO [15]. Whereas AASHTO PP 105 [12] frames BMD using four "approaches" that describe mix design methodology and how mechanical performance tests are incorporated into the mix design process, the proposed standard focuses on how agencies specify and implement BMD mixtures, thereby allowing greater flexibility in mix design. A three-tier structure was proposed that reflects increasing levels of specification maturity and permitted flexibility in constituent selection and volumetric requirements. As agencies advance through the "tiers," reliance progressively shifts from constituent and volumetric controls toward mechanical performance testing. This tiered framework is viewed as a practical pathway for phased implementation, enabling agencies to align performance-testing requirements with readiness, contractor capability, and risk tolerance. Three tiers are described as follows:

- **Tier 1**—Baseline Requirements for BMD Specifications
  - Meets selected constituent, volumetric, and mechanical test requirements for performance characteristics.
  - Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.
- **Tier 2**—Increased Flexibility
  - Allows relaxation of certain constituent and volumetric requirements to provide more freedom in material selection and mix adjustments.
  - Emphasizes mechanical testing while reducing reliance on specific constituent and volumetric parameters.
  - Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.

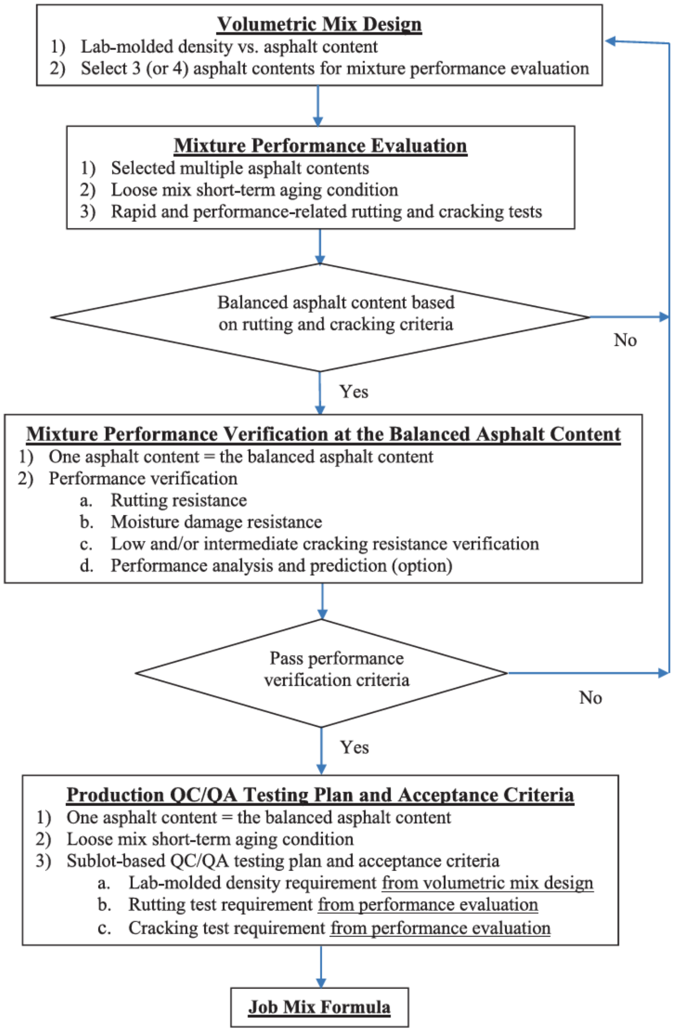
- **Tier 3**—Performance-Driven Design
  - Minimizes detailed constituent and volumetric requirements, with primary reliance on performance-based material and design optimization, and mechanical testing to validate mixture performance.
  - Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.

Despite these advancements, a significant challenge remains in implementing performance tests on plant-produced mixtures during BMD-based quality assurance and quality control (QA/QC). These tests must be conducted within tight construction schedules, requiring efficient procedures and reliable equipment. The limited time frame and operational constraints often hinder the widespread adoption of performance testing in routine QA/QC processes. To formalize and support BMD implementation, AASHTO published provisional Standard Practice PP 105-20 [12] in 2020, which outlines the procedures and requirements for all four BMD approaches, offering a consistent pathway from mix design through construction acceptance.

Quality Assurance and Quality Control in the BMD Framework

Quality assistance and quality control (QA/QC) are essential to successful BMD implementation, as they ensure that the performance characteristics established during mix design are consistently achieved during production and construction. QA/QC are critical components that involve owner agency-led and contractor-led testing and monitoring during asphalt mix production and placement, respectively, to ensure materials and processes meet volumetric and performance specifications. Several studies have sought to integrate BMD principles with QA/QC practices to ensure consistent asphalt mixture performance during production. Based on prior knowledge and plant-level experience, Zhou et al. [16] proposed a structured framework (Figure 2) that aligns BMD with QA/QC processes composed of four key components: (1) volumetric mix design as the initial basis; (2) performance evaluation across a range of asphalt contents to identify an optimal, balanced asphalt content; (3) performance verification at the selected balanced asphalt content; and (4) development of a QA/QC testing plan with associated acceptance criteria. This structured approach facilitates the transition from lab-based mix design to production-scale quality management while maintaining a focus on performance.

Figure 2. Coherent framework for BMD/QA/QC [16]



AASHTO MP 46 [13] provides a framework by listing a range of rutting and cracking performance tests that agencies can adopt. While such tests are utilized for design validation, their implementation during QA/QC poses practical challenges, particularly regarding time constraints for evaluating plant-produced mixtures. Rutting resistance, which typically manifests early in a pavement's life, can be reliably assessed through the testing of field cores or compacted plant-produced specimens using tests like the Hamburg Wheel Tracking Test (HWTT) or Asphalt Pavement Analyzer (APA). These tests can be conducted within a relatively short timeframe and are generally compatible with QA/QC needs. In contrast, evaluating cracking resistance is more complex due to the influence of long-term aging (LTA). LTA simulates in-service aging caused by environmental and traffic loads and typically requires prolonged conditioning using protocols such as AASHTO R30 [6] and those developed under NCHRP Project 09-54 [7]. While effective for design purposes, these protocols are impractical for QA/QC because they take several days to complete, resulting in delays in acceptance decisions during production. Therefore, advancing BMD implementation for QA requires the development of practical LTA simulation strategies that can be executed within 24 hours, predictive models that estimate LTA behavior at day zero, or scaling factors to project LTA from early-age data. Additionally, the importance of region-specific testing, guided by FHWA's climate zone classifications shown in Figure 3 [17], highlights the need for tailored approaches, with low-temperature testing emphasized in freeze zones and intermediate-temperature testing prioritized in non-freeze regions.

Figure 3. FHWA defined four climate zones [17]

Asphalt mixture performance depends on both short-term aging (STA), which occurs during production and placement, and LTA, which develops over the pavement's service life. While STA can be simulated quickly and reliably for QA purposes, LTA remains a major barrier to timely, practical quality control. Therefore, integrating effective, accelerated LTA strategies with effective performance testing set into QA is critical to ensure that the designed performance of BMD mixtures is realized in the field, allowing agencies to make informed acceptance decisions that support long-term pavement durability. Meanwhile, simpler and more efficient performance tests, such as the IDEAL-CT for cracking and IDEAL-RT for rutting resistance, are increasingly favored in QA/QC practices due to their rapid testing procedures, monotonic loading protocols, simplified specimen conditioning, lower equipment costs, and simpler operational setup and result interpretation.

Selection of BMD Performance Tests

Given the wide range of asphalt mixture performance tests, a key task in BMD implementation is selecting methods that are economical, practical, and timely, while providing acceptable precision, repeatability, and a demonstrated relationship to field performance [10]. Accordingly, laboratory tests should be chosen based on their ability to quantify the relevant distress mechanisms and represent in-service pavement behavior for both mix design and quality assurance. The BMD process typically includes identifying dominant distress modes, selecting appropriate tests, evaluating mixture resistance, and establishing performance criteria for quality acceptance [18]. Test selection should consider environmental conditions (e.g., temperature and moisture), distress type (e.g., thermal and fatigue cracking, rutting), and loading characteristics. Selected tests should also be sensitive, reproducible, and capable of discriminating among mixtures with differing performance potential to support reliable performance prediction and durability.

Table 1 summarizes the performance tests commonly used to evaluate asphalt mixture resistance to cracking, rutting, and moisture damage, as expended based on the summaries by West et al. [19] and Liu et al. [20]. While not exhaustive of all tests used in the U.S., it highlights those most relevant to key pavement distress. A mix is considered “balanced” when it exhibits adequate resistance to both cracking and rutting, with adequate moisture damage resistance. To achieve this, performance thresholds should be established based on sound engineering judgment and field experience to ensure long-term pavement performance. Implementing BMD across different states involves both challenges and opportunities. One of the primary challenges is selecting tests that are appropriate for each state’s specific climate, traffic conditions, and materials, while also addressing the need for standardized protocols, trained personnel, and specialized equipment, particularly for tests with more stringent requirements. Variability in test results and integration into current specifications and QA/QC practices add to the complexity. Nonetheless, performance testing involves significant studies aimed at providing a strong foundation for improving pavement durability, supporting the use of innovative and recycled materials, and optimizing mix designs for local conditions. Simpler, more cost-effective tests such as IDEAL-CT, IDEAL-RT, and Cantabro offer practical starting points, enabling informed, data-driven decisions that improve performance and reduce long-term costs.

Table 1. Common performance tests for characterizing rutting, cracking, and moisture damage [19] [20]

Tests [19] [20]	Approximated total conditioning and test time [20]	Evaluation metrics [19]	Equipment cost [20]
Cracking tests			
Disk-shaped Compact Tension (DCT) ASTM D7313 [21]	4-5 days	Fracture energy	$50,000
Beam fatigue test AASHTO T321 [22]	3-5 days	Number of cycles (fatigue life)	>$100,000
Cyclic fatigue test AASHTO TP 107 [23]	4-5 days	Fatigue damage parameters	$85,000
Indirect Tensile Asphalt Cracking Test (IDEAL-CT) ASTM D8225 [24]	1 day	Crack tolerance index (CT Index)	<$10,000
IDT-University of Florida AASHTO T322 [25]	4-5 days	Energy ratio	>$100,000
Illinois flexibility index test (I-FIT) AASHTO TP124 [26]	2-3 days (including sample drying)	Flexibility index	<$10,000
Overlay test (OT) Tex-248-F [27]	3-4 days	Crack resistance index	$50,000
Semi-Circular Bend (SCB) AASHTO TP105 [28]	3-4 days	Fracture energy	$100,000
SCB-J_c ASTM D8044 [29]	7-8 days (including 5 days aging @ 85°C)	J_c-critical strain energy release rate	$10,000
Simplified Viscoelastic Continuum Damage (S-VECD) Sabouri and Kim, 2014 [30]	-	Damage characteristic curve (C vs. S), energy-based indices	$100,000
Rutting Tests			
Asphalt Pavement Analyzer (APA) AASHTO T340 [31]	2 days	Rutting depth (mm) after a set number of wheel passes (typically 8,000 cycles)	>$100,000
Hamburg Wheel Tracking Test (HWTT) AASHTO T324 [32]	2 days	Rut depth after 20,000 cycles or at failure, stripping inflection point (SIP)	$50,000
Rapid Shear Rutting Test (IDEAL-RT) ASTM WK71466 [33] (in development)	1 day	RT Index	<$10,000
High Temperature Indirect Tensile Strength Test (HT-IDT) Agency-specific	1 day	IDT strength at high temperature	<$10,000
Flow Number Test (FN) AASHTO T378 [34]	4 days	Flow number (FN), creep slope	$85,000
Hveem Stability Test AASHTO T246 [35]	-	Hveem stability value	-

Repeated Load Triaxial Test (RLT) AASHTO T307-99 [36]	-	Permanent deformation (strain) vs. cycles, elastic modulus	-
Marshall Stability Test AASHTO T245 [37]/ ASTM D6927 [38]	1 day	Marshall stability, flow value	<$10,000
Moisture Damage Tests			
Tensile Strength Ratio (TSR) AASHTO T283 [39]	3-4 days	Tensile Strength Ratio (TSR)	<$10,000
Hamburg Wheel Tracking Test (HWTT) AASHTO T324 [32]	2 days	Rutting depth, stripping inflection point	$50,000
Cantabro Test ASTM D7064 [40]or AASHTO TP 108 [41] (for OGFC)	-	Mass loss (%) after 300 revolutions (or other specified cycles)	$10,000
Modified Lottman Test AASHTO T283 [39] (Modified)	3-4 days	Tensile Strength Ratio	<$10,000

Aging Effect of Binder and Asphalt Mixture

Asphalt Binder Aging Mechanisms

Asphalt binder is the primary component in asphalt mixtures affected by aging, making its chemical and rheological characterization essential for understanding pavement aging behavior. Aging is driven by environmental exposure such as oxidation, ultraviolet (UV) radiation, and temperature fluctuations. Oxidation, the dominant aging mechanism, leads to the formation of polar functional groups like carbonyls and sulfoxides, increasing binder stiffness and brittleness by raising the asphaltene content [42] [43]. In essence, oxidation induces both chemical and physical transformations that lead to asphalt mixture hardening and the formation of highly polar, oxygen-containing chemical fractions [44]. This process is especially pronounced at the pavement surface due to higher exposure to heat and sunlight (i.e., UV exposure).

Two primary methods are commonly employed to characterize asphalt binder aging: chemical and rheological. Fourier Transform Infrared Spectroscopy (FTIR) is used to detect changes in carbonyl and sulfoxide functional groups, which serve as indicators of oxidative and ultraviolet (UV) aging [44]. High-Pressure Gel Permeation Chromatography (HP-GPC) provides insights into changes in the binder's molecular composition, specifically for the transformation of maltenes and asphaltenes due to aging. Studies have consistently shown that aging increases the medium molecular weight fraction, such as asphaltenes, while reducing the low molecular weight fraction, such as maltenes [45]. From a rheological perspective, Elwardany [46] demonstrated that the dynamic shear modulus G^* measured at 64°C and 10 Hz is an effective parameter for tracking changes in binder properties associated with aging. Sensitivity analysis identified a 15% change in G^* as a reliable threshold that serves as a meaningful indicator of changes in mixture performance. The evolution of the dynamic viscosity-to-storage modulus ratio, along with changes in the storage modulus, has been shown to be utilized as a reliable indicator of ductility loss over time, which increases the susceptibility of asphalt binders to cracking [47]. Many other binder aging characterization methods were developed based on rheological properties of binder, such as $G'/(\eta'/G')$ [48] and the Glover-Rowe (G-R) parameter [49], which were widely adopted as a rheological index for aging-induced hardening.

Aging Simulation of Asphalt Mixture

In field applications, asphalt mixtures experience a two-stage aging process. The first stage, short-term aging (STA), occurs at elevated temperatures during production, transportation, placement, and compaction. The second stage, long-term aging (LTA), occurs gradually over the pavement’s service life, driven by site-specific climatic and environmental conditions. To simulate these aging stages for performance testing, State Highway Agencies (SHAs) and researchers have developed and adopted a variety of laboratory aging protocols for both loose mix and compacted specimens. However, major challenges, such as specimen integrity issues, particularly geometric distortion [50] during aging, and the development of oxidation gradients [44] that cause uneven aging within compacted samples, have led researchers to conclude that aging loose asphalt mixtures provides a more accurate simulation of field aging conditions [7].

Several studies, including those by Zhou et al. [16] and Kim et al. [7], have proposed and evaluated accelerated laboratory aging procedures with slight modifications to better reflect in-service aging conditions in different stages, such as production, transportation, placement, compaction, and in-service life, driven by site-specific climatic and environmental conditions. A summary of these procedures is presented in Table 2. The table ranks the aging methods according to duration. It has been found that asphalt mixtures can be conditioned at elevated temperatures for shorter durations to achieve aging levels comparable to those observed in the field, making these approaches more practical for laboratory simulation of asphalt aging. Moreover, Table 2 highlights two critical gaps: (1) a wide variety of aging methods both for STA and LTA, and (2) a lack of a nationally or internationally standardized protocol for assessing both STA and LTA in asphalt mixtures. These gaps pose challenges to the implementation of BMD performance tests and hamper the comparability of results across agencies and studies.

Table 2. A selection of accelerated laboratory aging procedures developed for loose mixtures and compacted specimens

Aging Type	Duration	Temperature	Sample Type	Reference
STA	1.5-h	135°C	Loose mixes	Belgian Road Research Center [51]
	2-h	135°C (HMA) 116°C (WMA)	Loose mixes	AASHTO R 30 [6]
		@ compaction temp.	Loose mixes	TxDOT Specifications 2014 [52]
	2-h	116°C	Loose WMA	Epps-Martin et al. [53]
	2-h	135°C	Loose HMA	Newcomb et al. [54]
	4-h, 3-h	135°C, 130°C	Loose mixes	EMPA (Van den Bergh [55])
	4-h	135°C	Loose mixes	AASHTO R 30 [6]
				Bell et al. [56]
				Such et al. [57]
				Mollenhauer and Mouillet [58]
LTA	5-h	163°C	Compacted specimens	Mugler et al. [59]
	8-h	135°C	Loose mixes	Chen et al. [60]
	16-h	160°C	Loose mixes	Van Gooswilligen et al. [61]
	16-h	110-120°C	Compacted specimens	EMPA (Van den Bergh [55])
	20-h	110-125°C	Loose mixes	Zhou et al. [62]
	20-h	90°C	Loose mixes (PAV)	Braham et al. [63]
	24-h	100°C	Loose mixes	Such et al. [57]
	24-h	135°C	Loose mixes	Braham et al. [63]
	24-h	95°C	Compacted specimens	Al-Qadi et al. [64]
	24- to 696-h	95°C	Loose mixes	Kim et al. [7]
	60-h	60°C	Compacted specimens	TRL (Nicholls [65])
	65-h	85°C	Compacted specimens	Collop et al. [66]
	72-h	95°C	Loose mixes	Al-Qadi et al. [64]
	120-h	85°C	Compacted specimens	AASHTO R 30 [6]
	168-h	85, 90°C	Loose mixes	Van den Bergh [55]
	168-h	48-h @ 60°C + 120-h @ 107°C	Compacted specimens	AAMAS (Von Quintus et al. [67])
	336-h	60°C	Loose mixes	Belgian Road Research Center [51]
	480-h	60°C	Compacted specimens	Hachiya et al. [68]

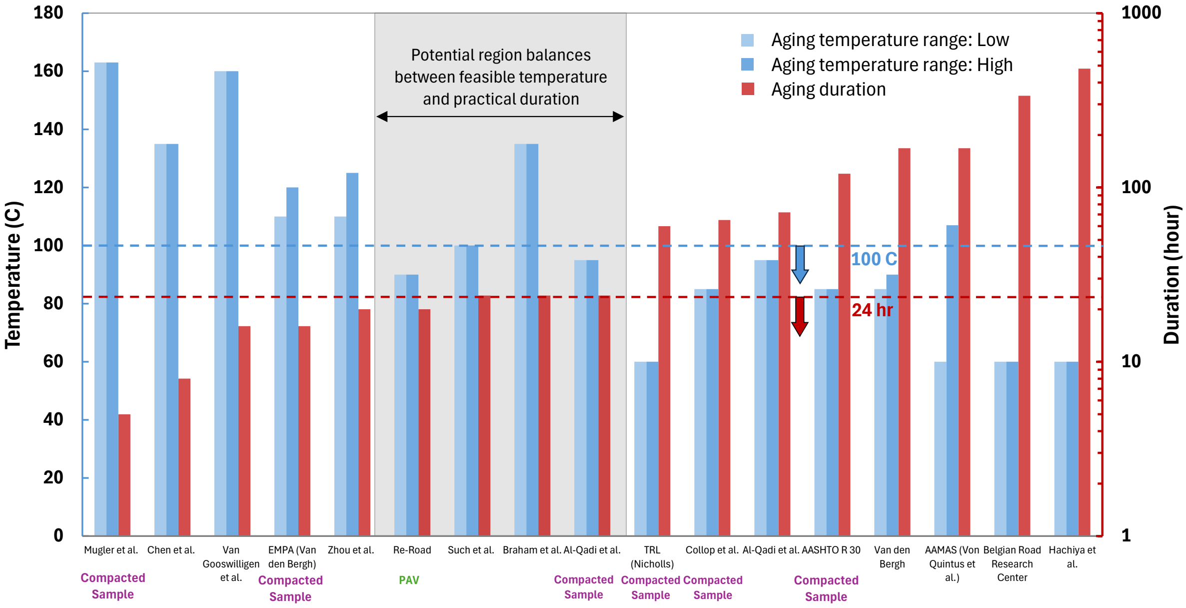
A comprehensive framework for nationwide BMD-based QA/QC, establishing a reliable conditioning procedure that accurately simulates field aging during production, is essential to ensure the effectiveness of BMD QA. For STA, conditioning loose mixtures at 135°C for four hours has been the standard practice (ASSHTO R30 [6]) and was endorsed by NCHRP Project 09-54 as the basis for STA simulation in mechanical property testing [7]. AASHTO R 30 was later reduced to two hours in its 2022 edition. The method remains widely accepted by SHAs and the asphalt industry, with improved feasibility for QA/QC timelines.

Appropriate and practical LTA simulation remains more challenging. NCHRP 09-54 [7] recommends 95°C conditioning for one day to 20+ days to replicate four to 16 years of field aging at 6 to 50 mm depths to match the amount of field aging based on depth and geographic locations, with 50 mm selected due to stabilized aging gradients below this depth. Since pavements typically show critical cracking at approximately 12 years (i.e., approximately two-thirds of a 20-year design life), Zhou et al. [62] developed a more practical 20-hour aging protocol at modified temperatures to match the aging effects of NCHRP 09-54's recommended three-day conditioning at 95°C, making the procedure feasible for standard workweek implementation. Chen et al. [60] proposed an alternative LTA protocol involving loose mixture conditioning at 135°C for eight hours, which they found comparable to the standard 95°C/five-day method. However, this elevated temperature approach raises concerns about potential distortion of oxidative reaction kinetics and its ability to accurately simulate long-term field aging under ambient conditions [69].

The bar chart in Figure 4 presents a comparative illustration of laboratory long-term aging protocols/methods for asphalt mixtures, highlighting both the aging temperature range and duration reported across multiple studies listed in Table 2. The blue bars represent the range of aging temperatures (i.e., low and high bounds) used in each method, while the red bars indicate the corresponding aging durations in hours, displayed in ascending order on a logarithmic scale on the secondary axis. The chart illustrates substantial variability in both temperature and duration across different protocols for simulating long-term aging. Notably, some methods are conducted on compacted asphalt samples, as emphasized in the plot, while others, such as the approach by Mollenhauer and Mouillet [58], utilize a Pressure Aging Vessel (PAV) for aging. Overall, despite the observed variability among protocols, the general trend indicates that higher conditioning temperatures require shorter aging durations to achieve comparable in-field aging effects.

BMD QA/QC requires timely implementation to support efficient laboratory simulation. Among existing long-term aging (LTA) protocols, especially for cracking resistance tests, aging durations of 24 hours or less are considered more operationally feasible in the laboratory. As such, 24 hours can be viewed as a practical upper bound for BMD QA applications; see the red dashed line in Figure 4. From a temperature standpoint, studies have indicated that aging loose mixtures at elevated temperatures may not be suitable for asphalt mixtures due to the risk of thermal degradation of modifiers and additives, such as styrene-butadiene-styrene (SBS) [70]. Further, excessive aging temperatures can lead to asphalt mastic drain-down in loose mixtures, caused by the significantly reduced viscosity of the asphalt binder under such conditions [7]. Therefore, for illustrative purposes, 100°C (indicated by the blue dashed line in Figure 4) is used as the upper bound of feasible conditioning temperature, although the actual temperature applied in practice may be higher. In Figure 4, the aging durations are arranged in ascending order. A gray shaded region marks a potential target zone where protocols balance feasible temperatures and practical durations, suggesting a compromise between laboratory efficiency and realistic aging simulation. Horizontal dashed lines at 100°C (blue) and 24 hours (red) serve as reference thresholds frequently cited in practice.

Figure 4. Comparison of aging duration and aging temperature of accelerated laboratory long-term aging procedures developed for loose mixtures and compacted specimens



Factors Influencing Asphalt Mixture Aging

The aging of asphalt mixtures is influenced by a combination of mix design variables, production methods, and environmental conditions. These influencing factors are further categorized into multiple interconnected factors, including:

- **Mixing time and temperature:** Mixing temperatures at the asphalt plant significantly influence the short-term loss of volatile components and affect the subsequent rate of oxidation [71]. Additionally, mixing time impacts the extent to which binder-coated aggregates are exposed to oxygen. According to the Hot-Mix Asphalt Handbook [72], once the binder is properly distributed, extending the mixing time does not improve coating effectiveness but instead increases the potential for oxidative hardening.
- **Asphalt binder grade:** softer binder requires lower mixing temperature but is more susceptible to aging [73].
- **Plant type:** differences in the aging effects between drum plants and batch plants have been studied [74] [75] [76], with findings suggesting that drum plants generally induce less aging in asphalt mixtures compared to batch plants.
- **Aggregate gradation and absorption:** aggregate gradation on the finer side under a given nominal maximum aggregate size (NMAS) results in a larger surface area that is directly related to more exposure of asphalt to oxygen and a higher level of aging [77]. Finer aggregate gradations tend to produce asphalt mixtures with larger film thickness. Kandhal and Chakraborty [78] observed that asphalt film thickness significantly affects the rate of oxidative aging, with thicker film thickness requiring longer durations to undergo hardening due to slower oxidation.
- **Air void content:** has been shown to significantly influence the long-term aging (LTA) behavior of asphalt mixtures. Results from NCHRP Project 9-23 [71] demonstrated a strong correlation between higher air void levels and accelerated oxidative aging. Consistent findings were reported in studies conducted in Oklahoma [79] and California [80], where increased air void content was associated with greater binder stiffening over time.
- **Use of recycled materials or modifiers:** RAP content plays a significant role in the performance and aging behavior of asphalt mixtures. Studies have shown that as RAP content increases, the mixtures become less susceptible to stiffness gains during aging, slower aging rates, and reduced hardening compared to virgin mixtures [81] [82]. Polymer modification also influences aging behavior. Polymer-modified binders exhibit lower aging susceptibility than unmodified asphalt binders, which demonstrated enhanced performance in multiple stress creep and recovery tests, showing improved creep strain recovery and reduced non-recoverable deformation [83] [84].
- **Pavement depth:** The Global Aging System (GAS) model [85] and the Mechanistic-Empirical Pavement Design Guide (MEPDG) premise that aging primarily occurs within

the top 1 to 1.5 in of the surface [86]. A field investigation found that binder viscosity decreased by approximately 48 to 70% when comparing the surface 12 to 13 mm (0.5 in.) to the adjacent layer between 12 and 25 mm depth [7]. From a mechanistic perspective, the depth-dependent aging gradient is driven by the diffusion-limited ingress of oxygen and heat transfer, controlled by factors such as air voids and aggregate thermal conductivity [87].

These factors collectively contribute to the aging of asphalt mixtures from the point of plant production through the end of the pavement's service life. From a BMD QA/QC standpoint, understanding how each of these elements contributes to aging is essential for selecting performance tests, establishing aging protocols, and setting acceptance criteria that ensure mixture durability and field performance over time.

Current Developments of Balanced Mix Design from Literature

As Balanced Mix Design (BMD) continues to gain momentum nationwide, state-level adoption varies widely, driven by each DOT's specific needs, priorities, and available resources. This variation in approach and stage underscores a tailored strategy across states, balancing innovation potential, logistical constraints, and risk tolerance within their unique operational contexts [1]. Several states have confirmed the feasibility of BMD and are progressing toward state-level implementation of specific approaches; see Table 3. The table provides a comparative overview of both anticipated and current BMD adoption across the United States, based on data from 2023 peer exchange surveys [88] [89] [90] [91] [92] [93] and the 2025 National Asphalt Pavement Association (NAPA) website [94], respectively, with an emphasis on highlighting SASHTO member states in bold. While there is overlap between the two sources, considerable discrepancies exist in state-level reporting, which may reflect evolving implementation or differences in data-collection periods. The categorization by approach (i.e., A through D) suggests a spectrum of adoption complexity, with some states implementing and evaluating multiple BMD approaches reflected in peer exchange surveys conducted in 2023. Notably, many states have implemented Approach A. In 2025, most states are still in the process of pre-implementation verifying BMD methodologies. Rather than fully adopting a true BMD framework, they primarily rely on cracking and rutting tests within their design processes [94]. Significant changes from one BMD approach to another are observed in many states' feedback between the two surveys. This table highlights the diversity of BMD implementation pathways across the United States, reflecting a gradual progression toward the potential standardization of performance-based mix design practices.

Table 3. Anticipated state-level implementation of BMD approaches retrieved from peer exchange surveys in 2023 [88] [89] [90] [91] [92] [93]and NAPA website in 2025 [94]

Approach	State
Information retrieved from the peer exchange surveys in 2023	
Approach A	**Alabama, Louisiana,** Pennsylvania, Arizona, Washington, Illinois, Michigan, Minnesota, South Dakota
Approach A & B	Massachusetts, New Hampshire, New Jersey, Colorado, Indiana, Wyoming
Approach A, B & C	Vermont, Nevada, Utah, Ohio
Approach A & C	New York
Approach B	Missouri, North Dakota

Approach B & C	**Texas**, Oregon
Approach B, C & D	Montana
Approach B & D	**Oklahoma**
Approach C	**Georgia,** Wisconsin, California
Approach C & D	**Arkansas**
Approach D	**Tennessee**, Idaho
TBD	**Mississippi**, Maine, Nebraska, Connecticut
Information retrieved from the NAPA website in 2025	
Approach A	**Texas**, **Louisiana**, **Kentucky,** Wisconsin, Illinois, New York, Vermont
Approach B	**Virginia,** Oklahoma, Missouri
Approach C	**Alabama**, California
Approach D	-
Approach A&B	New Jersey
Pre-implementation	**Arkansas**, **Mississippi**, **Tennessee**, **North Carolina**, **South Carolina**, **Georgia,** Washington, Oregon, Idaho, Montana, North Dakota, South Dakota, Utah, Colorado, New Mexico, Iowa, Ohio, Kansas, Pennsylvania, Maine, Massachusetts, Maryland
Note: The member states of the Southern Association of State Highway and Transportation Officials (SASHTO) are highlighted in **bold**.	

Based on the regional Peer Exchanges [88] [89] [90] [91] [92] [93] on BMD implementation, Table 4 provides a comprehensive summary of BMD implementation efforts across seven SASHTO member states, highlighting the diverse testing approaches, standards, aging protocols, performance criteria, and utilization practices for rutting, cracking, moisture damage, and friction evaluation. A more comprehensive summary, including other states in the United States, is listed in Table A1 in the Appendix. From the table, many states were still evaluating different BMD approaches, using performance tests such as the HWTT, IDEAL-CT, SCB-J_c, Overlay Tester, and APA, with aging typically conducted per AASHTO R 30. Criteria for acceptance vary by binder grade, traffic level, and agency-specific thresholds. States such as Alabama and Tennessee apply tests primarily during design or are still evaluating rapid alternatives for acceptance. Moisture resistance is commonly assessed through TSR, and Tennessee was exploring the use of friction testing (e.g., DFT) in the BMD process.

Table 4. Summary of BMD implementation in SASHTO states based on regional Peer Exchanges on Balanced Mix Design [88] [89] [90] [91] [92] [93]

BMD Approach	State	Testing		Testing Standard	Aging	Test Criteria	Test Utilization and Consistency
Approach A	**AL**	**R**	Hamburg HT-IDT	AASHTO T 324 ALDOT 458	**Hamburg** and **HT-IDT**: AASHTO R30 2-h@135°C	**Hamburg**: Mixes with 67-22 Binder < 10mm at 10,000 passes Mixes with 76-22 binder < 10mm rutting at 20,000 passes **HT-IDT**: TBD	Rutting NOT tested during acceptance
		C	IDEAL-CT	ASTM D8225-19	AASHTO R 30 2-h @135°C	TBD : ESAL Range A/B: 50 ESAL Range C/D: 75 ESAL Range E: 100	Cracking NOT tested during acceptance
		M	TSR HWTT	AASHTO T 283 AASHTO T324	N/A.	– **TSR** : 0.80 – **HWTT**: Mixes with 67-22 Binder < 10mm at 10,000 cycles. Mixes with 76-22 binder < 10mm rutting at 20,000 passes.	TSR is used for design and acceptance
Approach A	**LA**	**R**	HWTT	AASHTO T324	AASHTO R30 –STA 4-hr	**Lv 2:** (high traffic) <6mm @ 20,000 passes **Lv 1**: (low traffic) <10mm @ 20,000 passes	Must pass prior to production. Verified during production.
		C	SCB-Jc	ASTM D8044	AASHTO R30 –LTA 5 days – 85°C	**Lv 2**: (high traffic) Jc>0.6 kJ/m2 **Lv 1**: (low traffic) Jc>0.5 kJ/m2	Must pass prior to production.
		M	HWTT	AASHTO T324	AASHTO R30 –STA	No stripping inflection point	Must pass prior to production. Verified during production.
Approach B & C	**TX**	**R**	HWTT IDEAL-RT.	Tex-242-F ASTM D8360	2 hours short-term oven aging at compaction temperature.	**HWTT**, Max 12.5mm rut: – @ 10,000 for PG 64. – @ 15,000 for PG 70. – @ 20,000 for PG 76. **IDEAL-RT**: – 60 for PG 64 or lower. – 65 for PG 70. 75 for PG 75 or higher.	Same test used during mix design and acceptance.
		C	Texas OT IDEAL-CT	Tex-248-F; Tex-250-F	2 hours short-term oven aging at compaction temperature.	**Texas OT**: – CFE > 1. – CPR < 0.45. **IDEAL-CT**: – 80 for PG -22 or higher. 100 for PG -28 or lower.	
Approach C	**GA**	**R**	HWTT	AASHTO T324	-	– PG 64-22 & PG 67-22, 4.75 mm, 9.5 mm SP Type I, and Type II, ≤ 12.5 mm, 15,000 passes, SIP > 15,000 Passes – PG 64-22 and PG 67-22, 12.5 mm SP, 19 mm SP and 25 mm SP, ≤12.5 mm, 20,000, SIP > 20,000 Passes – PG 76-22, All Mix types, ≤ 12.5 mm, 20,000, SIP> 20,000 Passes.	-
		C	IDEAL-CT	ASTM D8225	-	– State Routes (Non-controlled access) <10,000 ADT, 4.75 mm and All Superpave Mix Types: ≥ 50. – State Routes (Non-controlled access) ≥10,000 ADT, All Superpave Mix Types: ≥ 70. – Interstates and Controlled Access State Routes, All Superpave Mix Types: ≥ 100. – Interstates and Controlled Access State Routes, All SMA Mix Types: ≥ 150.	-
		M	TRS	AASHTO T 283	-	– >0.8 – >0.7 for if all individual strength values > 100 psi.	-
Approach C & D	**AR**	**R**	APA	AHTD 480	AASHTO R30 2h @ compaction temp.	Two 150mm by 75mm specimens; 100 psi hose pressure; 8000 cycles	Rutting NOT tested during acceptance.
		C	IDEAL-CT	ASTM D8225-19	AASHTO R 30 4- h@135°C	**-**	In verification process and QA for information only.
		M	Retained Stability	Modified T245	None	100 psi hose pressure; 8000 cycles	Used for mix verification during first 90 days of production

Approach D	**TN**	**R**	HWTT	AASHTO T324	AASHTO R30 – 2-h	<12mm rutting @ 50C Min passes req'd changes by road AADT. (10/15/20k)	Probably different tests used for mix design and acceptance. Evaluating for a quick test for acceptance.
		C	IDEAL-CT	ASTM D8225	AASHTO R30 – 4-h	–< min 50/75/100 Depending on road AADT. –Considering a peak load requirement.	Probably IDEAL-CT for mix design and acceptance.
		M	HWTT	AASHTO T324	AASHTO R30 – 2-h	SIP may occur but only beyond 10k passes, all roads	Probably different tests used for mix design and acceptance. TSR
		F	DFT (TBD)	ASTM E1911	TBD	–Research underway. –Most likely some level of friction achieved at a design polishing with a Three Wheel Polisher.	N/A
TBD	**MS**	**R**	TBD (APA, HWTT, IDEAL-RT, and HT-IDT)	TBD	AASHTO R30 –STA 2-h	-	IDEAL-RT or HT IDT for production.
		C	IDEAL-CT	ASTM D8225-19	AASHTO R30 –STA 2-h	-	IDEAL-CT during mix design and acceptance.
		M	–Hamburg Cantabro	AASHTO T324 AASHTO TP 108-14	AASHTO R30 –STA 2-h	-	Both for mix design and possibly Cantabro for production.
SASHTO States where BMD implementation status is not included.				FL, HI, KY, NC, SC, VA, WV			
Annotation							
R: rutting **C**: cracking **M**: moisture **F**: friction		**APA**: Asphalt Pavement Analyzer **HWTT**: Hamburg Wheel-Tracking Test **IDT**: Indirect Tensile Test **HT-IDT**: High-Temperature Indirect Tensile Test **IDEAL-CT**: Indirect Tensile Asphalt Cracking Test **IDEAL-RT**: Indirect Tensile Asphalt Rutting Test **ITS**: Indirect Tensile Strength **IMC**: Index for Moisture Condition **OT**: Overlay Tester				**RLT**: Repeated Load Triaxial **FBF**: Fatigue Beam Fatigue **DFT**: Dynamic Friction Tester **TSR**: Tensile Strength Ratio **ST**: Tensile Strength **I-FIT**: Illinois Flexibility Index Test **SCB-Jc**: Semi-Circular Bend Test **DCT**: Disk-Shaped Compact Tension Test	

Figures 5 through 7 present an overview of the evolution of state-level BMD implementation by DOTs, detailing anticipated adoption of BMD approaches, rutting performance tests, and cracking performance tests, respectively. This summary is based on insights from the 2023 Peer Exchanges [88] [89] [90] [91] [92] [93] and the NAPA survey as of June 2025 [94]. During the 2023 peer exchange, most state DOTs reported still piloting multiple BMD approaches to identify those best suited to their local conditions. By June 2025, the majority of states remained in pre-implementation, seven states are following Approach A, four have adopted Approach B, and two have implemented Approach C. For the rutting performance test, HWTT and APA are the two most popular rutting tests in both the 2023 peer exchanges and the 2025 NAPA survey. For cracking assessments, IDEAL-CT, BBF, OT, and I-FIT tests appeared on the list of the most commonly used test protocols. Concurrently, rapidly deployable rutting tests such as IDEAL-RT and high-temperature IDT (HT-IDT) are gaining traction in many states, due to their simplicity, efficiency, and strong correlation with traditional wheel-tracking tests. Overall, while full BMD adoption remains limited, states are progressively incorporating performance tests into their projects, signaling a shift toward performance-based specifications.

Figure 5. Anticipated adoption of BMD approaches in the U.S. based on (a) 2023 Peer Exchange [88] [89] [90] [91] [92] [93] and (b) NAPA survey in June 2025 [94]

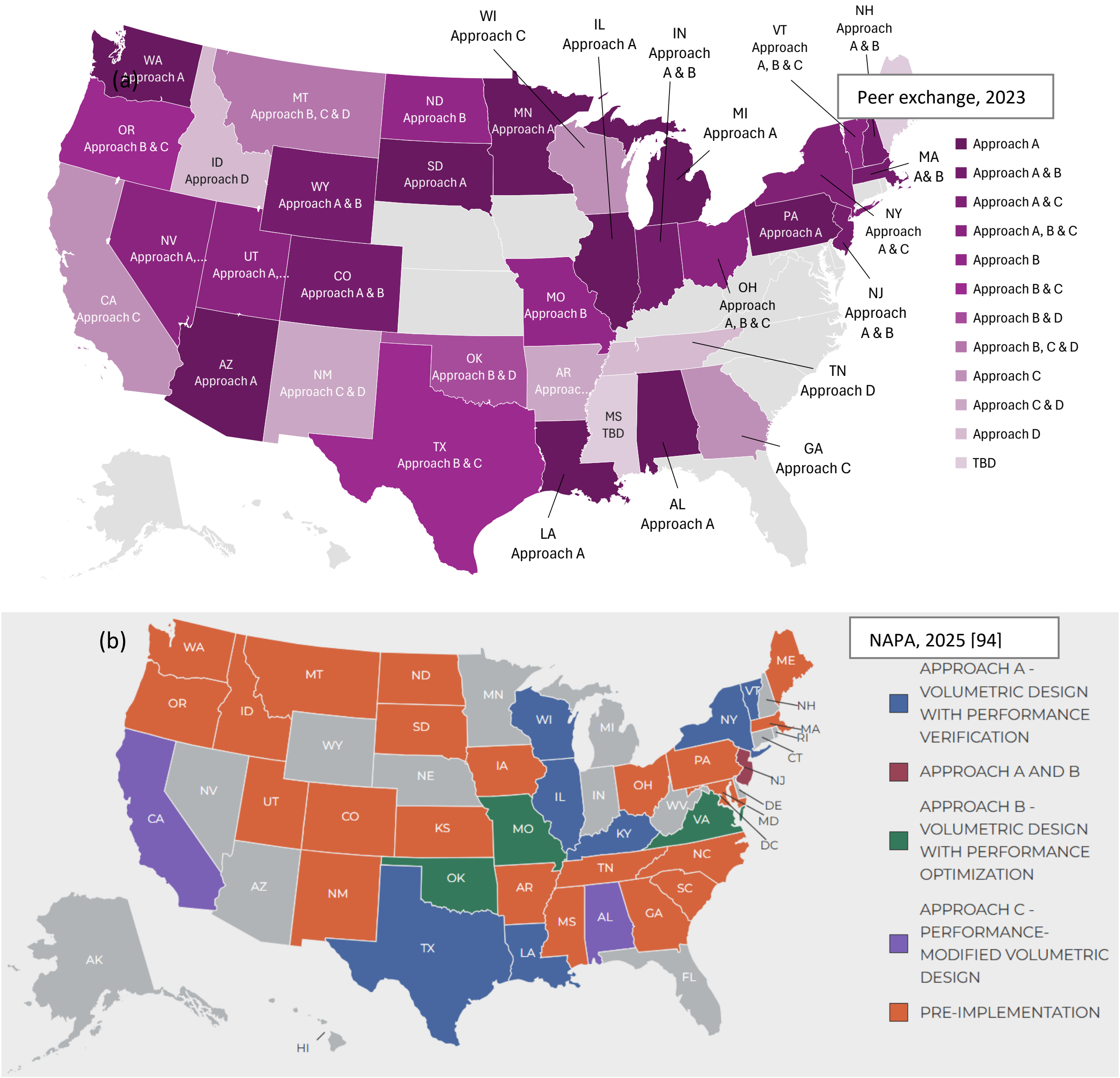


Figure 6. Anticipated adoption of rutting performance tests in the U.S. based on (a) 2023 Peer Exchange [88] [89] [90] [91] [92] [93] and (b) NAPA survey in 2025 [94]

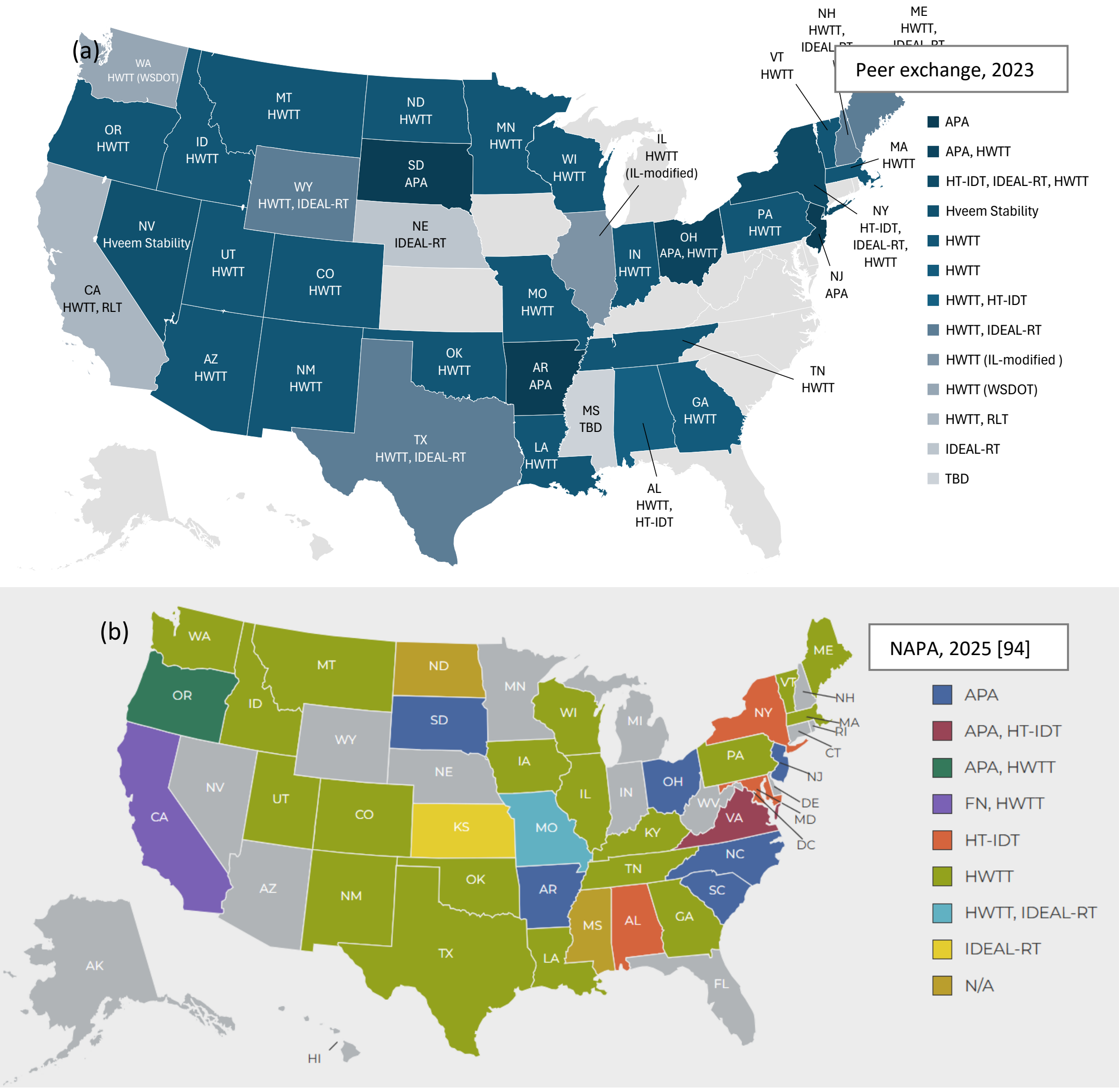
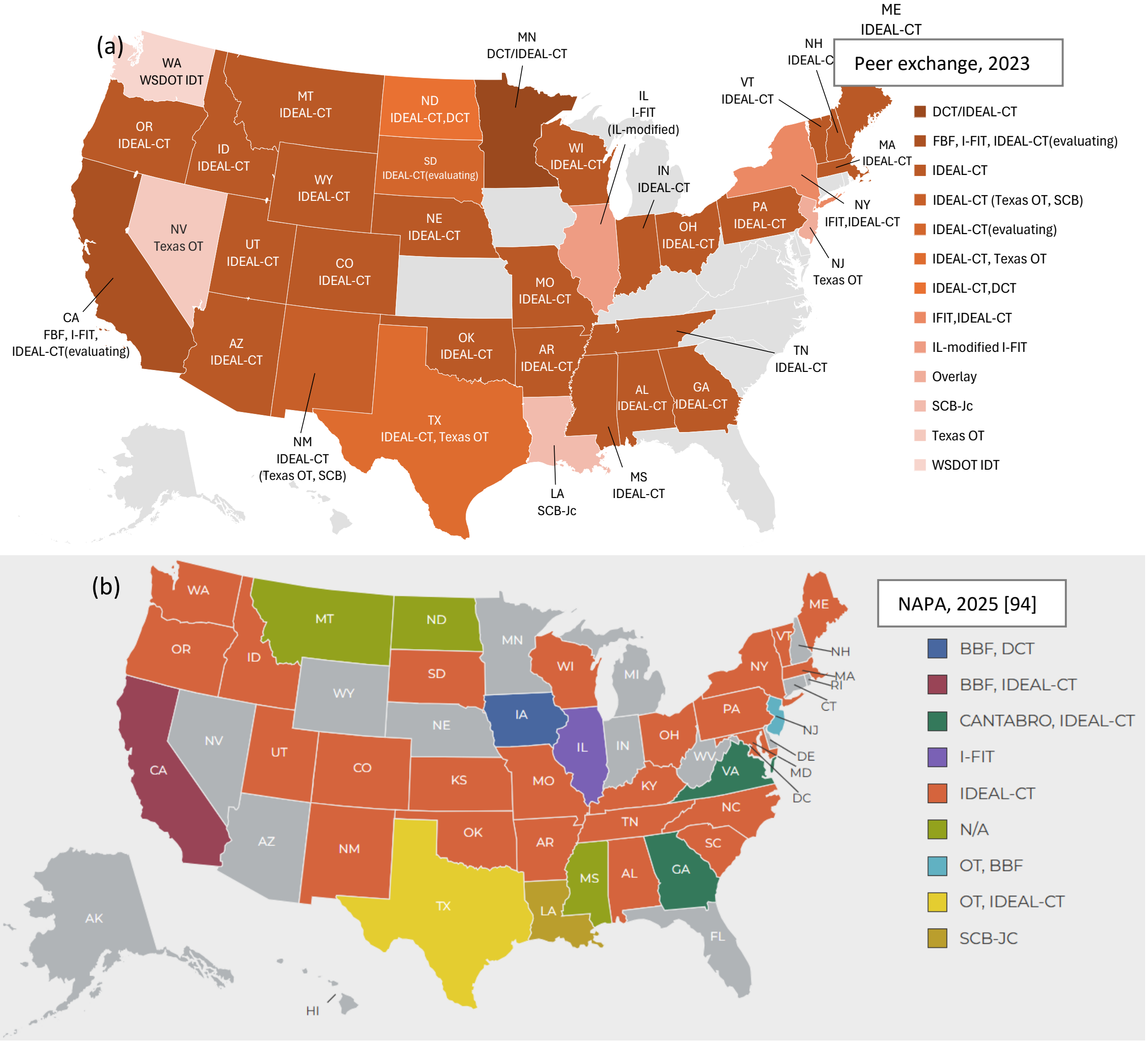
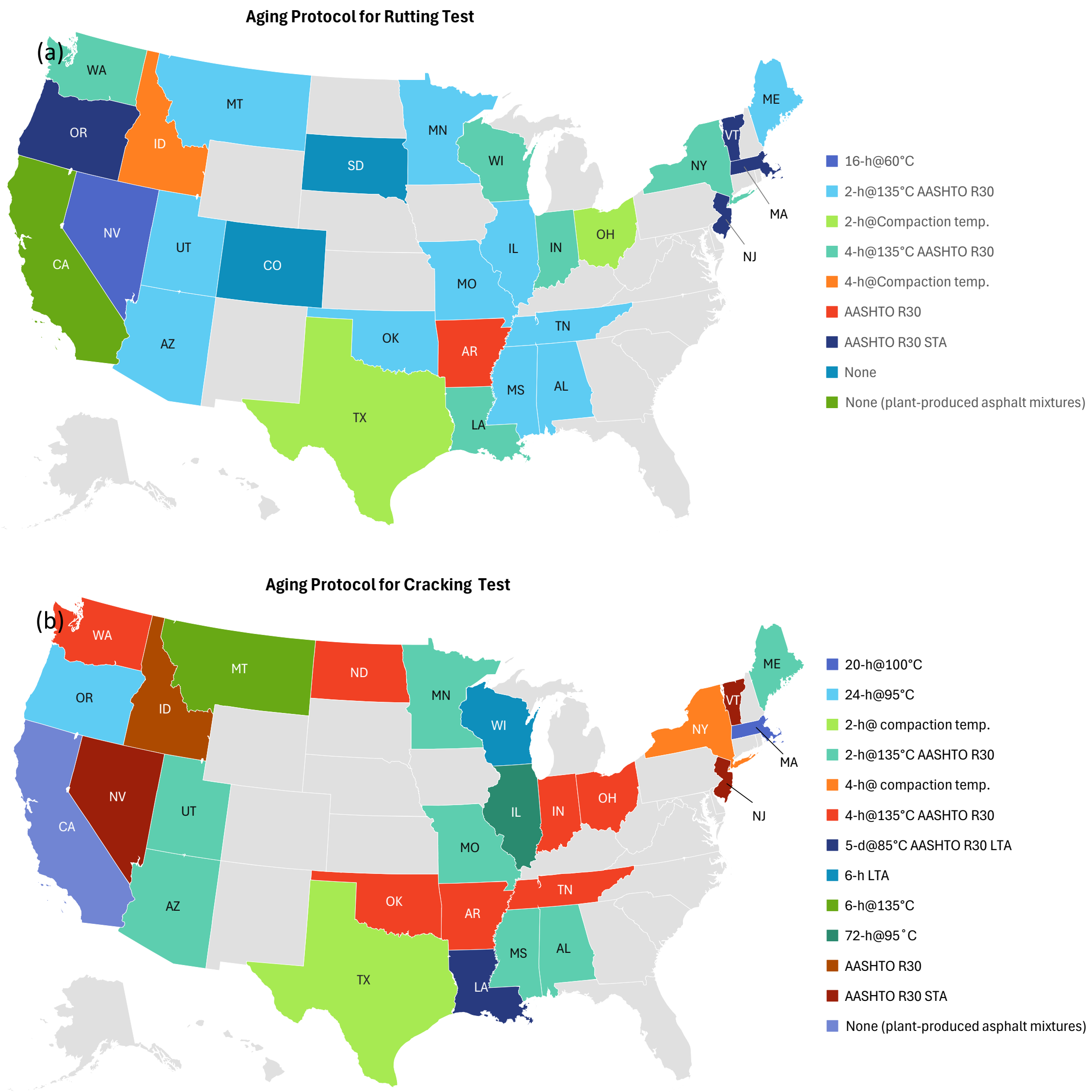


Figure 7. Anticipated adoption of cracking performance tests in the U.S. based on (a) 2023 Peer Exchange [88] [89] [90] [91] [92] [93] and (b) NAPA survey in 2025 [94]



As a core element of the BMD QA/QC framework, Figure 8 presents state-level aging protocols applied before rutting and cracking performance tests based on the feedback in the 2023 peer exchange [88] [89] [90] [91] [92] [93]. Short-term aging protocols for rutting exhibit considerable variability. Many states adhere to the AASHTO R 30 standard of two to four hours at 135 °C, while others opt for conditioning at compaction temperature (typically approximately 135 °C) to better represent actual plant conditions. Cracking test aging protocols show even greater diversity, spanning from short-term conditioning (e.g., two to four hours) to long-term oven aging over several days (e.g., 72 hours at 95 °C or five days at 85 °C). A few states bypass laboratory aging and test plant-produced specimens directly. This broad range of practices reveals the absence of a unified standard for BMD-related aging. Instead, many states are adopting both short- and long-term conditioning approaches to align with their specific performance goals and operational constraints.

Figure 8. U.S. map of aging protocol [88] [89] [90] [91] [92] [93] for (a) rutting performance tests and (b) cracking performance tests



State Research Projects on BMD

This section provides a summary of completed and ongoing state-based studies and projects, with particular emphasis on the southeastern region of the United States, while also encompassing nationwide efforts to compile research relevant to the Balanced Mix Design (BMD) framework. A comprehensive review of diverse sources, including academic publications, state DOT reports, and agency documentation, was conducted to identify both established practices and emerging developments. The review aims to narrow the synthesis to BMD-related topics, such as agency adoption status, selection and calibration of performance tests and thresholds, and strategies for QA/QC integration, ensuring the research remains focused and aligned with project objectives while addressing relevant aspects for SASHTO states. Table 5 lists the completed and ongoing state-based projects and research in SASHTO states and their BMD-related keywords. A comprehensive list of state-based projects and studies in the United States is provided in Table A2.

Table 5. Completed and ongoing state-based projects and research in SASHTO member states

State	Study Date	BMD-Related Key Words	BMD -Related Projects and Studies
VA	September 2025	Documenting full statewide BMD implementation, QA/QC data, adjustments/improvements to the specification, all SM-9.5, a white paper for future reference, SM-12.5 A and D surface mixes.	*Ongoing Project*: Documentation of 2024 Balanced Mix Design Implementation
	June 2025	Filed validation of BMD test criteria, FWD, asphalt content, gradation, mixture testing, and recovered binder properties.	*Ongoing Project*: Field Validation of Balanced Mix Design Initial Criteria
	July 2026	BMD framework, SBS modified dense-graded asphalt surface mixtures, high polymer modified asphalt mixtures, and cracking resistance test.	*Ongoing Project*: Developing a Balanced Mix Design (BMD) Framework for SBS Modified Dense-Graded Asphalt Surface Mixtures—Phase I
	March 2026	Reheating effects and isolation, impact on volumetric properties, dense-graded (A and D designations), BMD field trials, entity differences (producer, district, VTRC), mix batch differences.	*Ongoing Project*: Evaluating the Impact of Volumetric Properties and Reheating on the Balanced Mix Design Test Results
	December 2023	Fiber-reinforced materials, pavement performance, and tensile strength, using data from two pilot projects.	*Ongoing Project*: Balanced Mix Design for Surface Asphalt Mixtures—Fiber-Modified Mixtures

	December 2023	High RAP (up to 45%), recycling agent, rutting, cracking, durability, performance tests, APT, heavy vehicle simulator.	*Project*: Evaluation of Balanced Mix Design (BMD) Surface Mixtures with Conventional and High RAP Contents under Laboratory-Scale and Full-Scale Accelerated Testing [95]
	January 2025	Practical long-term aging protocols, IDEAL-CT, preliminary threshold, dense-graded (A and D designation), reheated plant-produced mixtures, mix design verification, QA/QC.	*Ongoing Project*: Developing Long-Term Aging Protocols for Cracking Performance Evaluation of Asphalt Mixtures in Virginia
	June 2024	Performance-based threshold criteria, pool of representative asphalt mixtures, correlation between empirical test results and fundamental tests, surrogate indices, Mechanistic-Empirical (ME) design, performance thresholds refinement.	*Ongoing Project*: Mechanistic-Based Evaluation of Performance Thresholds for Engineered Surface Asphalt Mixtures
	March 2023	Field trials, plant production, performance testing, high RAP contents, APA rut test, Cantabro test, IDEAL-CT.	*Project*: Balanced Mix Design for Surface Mixtures—2020 Field Trials
	June 2021	Field trials, plant production, performance testing, APA rut test, Cantabro test, IDEAL-CT.	*Project*: Balanced Mix Design for Surface Asphalt Mixtures—2019 Field Trials
	June 2023	Pilot projects, plant production, performance testing, APA rut test, Cantabro test, IDEAL-CT, QA/QC, acceptance.	*Project*: Balanced Mix Design for Surface Mixtures—2021 and 2022 Plant Mix Schedule Pilots
	May 2021	Initial roadmap, specification verification, performance testing, APA rut test, indirect tensile cracking test, I-FIT test, IDT N_{flex} test, dynamic modulus, Cantabro test, CT index.	*Project*: Balanced Mix Design for Surface Asphalt Mixtures: Phase I: Initial Roadmap Development and Specification Verification
	June 2023	Production variability, gradation and volumetric adjustment, IDT-CT; APA; Cantabro mass loss, variability, plant production.	*Project*: Impact of Production Variability on Balanced Mix Designs in Virginia
	January 2023	Rutting performance testing, alternative tests, HT-IDT, IDEAL RT, rapid rutting test, rutting tolerance index, APA, performance criteria.	*Project*: Simple and Practical Tests for Rutting Evaluation of Asphalt Mixtures in the Balanced Mix Design Process
LA	March 2021	Case studies, BMD implementation, selection of performance test, SCB, LWT, field performance relationship, interlaboratory study, training and certification.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures—Louisiana Department of Transportation & Development (DOTD)

	March 2024 to March 2025	Literature review, efficacy of IDEAL-CT and IDEAL-RT, volumetric properties, field vs. laboratory performance, LWT, SBC, aging, QA/QC.	*Project*: Literature Review of IDEAL-CT and IDEAL-RT Test Methods for Balanced Mixed Design
	June 2024	QC/QA; SCB J_c; scaling factor; long-term aging; cracking resistance; rheology; chemistry.	*Project*: Implementation of Semi-Circular Bend (SCB) Test for QC/QA of Asphalt Mixtures
	July 2019	RAP/RAS, low, intermediate, and high service temperatures binder and mixture tests, LWT, SCB.	*Project*: Evaluation of Asphalt Mixtures Containing Recycled Asphalt Shingles.
	April 2011 to September 2014	QC/QA, performance-based specification, a PBS implementation framework for LA, performance metrics, SCB, LWT, IDT, performance criteria, LA-PMS, calibration with 20-year projected distresses.	*Project*: Development of Performance-Based Specifications for Louisiana Asphalt Mixtures
GA	April 2022	Corrected Optimum Asphalt Content; IDEAL-CT; benchmark; CT index thresholds; high RAP content mixtures.	*Journal Paper*: Evaluating Impact of Corrected Optimum Asphalt Content and Benchmarking Cracking Resistance of Georgia Mixtures for Balanced Mix Design Implementation
AL	2022-	Field Trial Projects, IDEAL-CT, HT-IDT, acceptance, PMLC vs LMLC, correlation between performance test results and volumetric parameters.	*Field Trial Project*: Balanced Mix Design Field Trial Projects in Alabama
	2024-	QA testing program, pay assessment schedules.	*Ongoing Project:* Evaluation of Alabama Department of Transportation's Quality Assurance Testing Program and Pay Assessment Schedules for Asphalt Mixtures
	2018 to 2021	OGFC, SMA, dense-graded thin lay mix.	*Project:* Phase VII (2018-2021) NCAT Test Track Findings—Alabama DOT Sections
	April 2020	Rutting resistance and moisture susceptibility, HWTT, rut depth, field performance data correlations, criterion, laboratory repeatability.	*Journal Paper*: Determining the Relationship Among Hamburg Wheel-Tracking Test Parameters and Correlation to Field Performance of Asphalt Pavements
AR	December 2022	Cracking test, aging protocols (AASHTO R30 STA combined with the NCAT LTA), IDEAL-CT, rutting, APA, IDEAL-CT similar to SCB/IFIT system.	*Project*: Performance-Based Asphalt Mixture Design (PBD) for Arkansas

	August 2023	Compatibility (types of binders and aggregates), moisture resistance, maximum amount of sandstone aggregates, durability, Texas Boiling Test (TBT). dynamic modulus, HWTT, I-FIT, IDEAL-CT, TSR, and QC/QA.	*Project*: Effect of Aggregate-Binder Compatibility on Performance of Asphalt Mixtures in Arkansas
NC	August 2021 to December 2024	Performance metrics (cracking and rutting), construction projects, index-volumetrics relationships, performance volumetrics relationships, STA protocols (2 hr. STA better agreement between LMLC and PMLC), QA/QC, current tolerance limits for binder content and in-place density on performance, S_{app} and RSI.	*Project*: Performance Evaluation of HWY-2017-29 Project Asphalt Mixtures and Pavement
	August 2022 to July 2024	BMD framework, identify appropriate performance-related testing protocol for incorporation into mix design and QA/QC; initial threshold limits; draft BMD procedure, integrating performance tests into QA/QC operations.	*Project*: Balanced Asphalt Mix Design for North Carolina
OK	July 2018 to August 2019	Determining BMD test procedures, specifications and special provisions I-FIT, IDEAL CT.	*Project:* Implement Balanced Asphalt Mix Design in Oklahoma
	2018 to 2021	HWTT, I-FIT, IDEAL-CT, mixture: (1). 9.5 mm NMAS, PG 76-28 modified binder and 15% RAP, (2) 12.5 mm NMAS mix with PG 70-28 modified binder and 12% RAP, (3). 19 mm NMAS base course contains PG 64-28 modified binder with 30% RAP and a rejuvenator.	*Test Track Study:* Phase VII (2018-2021) NCAT Test Track Findings
	June 2024	Field performance of BMD mixes, 3D laser imaging technology, percentage cracking, IRI, rut depth, mean profile depth.	*Conference Paper:* Enhancing Pavement Performance through Balanced Mix Design—A Comprehensive Field Study in Oklahoma
	June 2024	Determining BMD test procedures, specifications and special provisions, I-FIT, CT Index.	*Conference Paper*: Pioneering the Evaluation of Balanced Asphalt Mix Design in Oklahoma
	August 2025	BMD specifications, select the asphalt cracking test, formulate procedures and benchmarks, long-term performance monitoring, short-term aging, field projects, round-robin for variability analysis.	*Dissertation:* Implementation of Asphalt Balanced Mix Design in Oklahoma—Progress, Challenges, and Future Prospects
TN	September 2023 to December 2025	Benchmarking of approved dense-graded asphalt mixtures, performance-based asphalt mixture design, PMLC vs LMLC, recommendations for performance criteria, IDEAL CT, TN CT, IDEAL RT, HWTT, HT-IDT.	*Project*: Benchmarking Study of TDOT D Mixtures for Balanced Mix Design

TX	March 2021	Case Study, BMD implementation.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures: Texas Department of Transportation (TxDOT)
	2018 to 2021	Test track study*,* BMD vs. the Superpave volumetric approach, HWTT, overlay tests. Mixtures: 9.5 NMAS mixes with the same PG 70-22 modified binder and 20% RAP binder replacement but different gradations and volumetric properties. BMD mix: 5.5% total binder content, Superpave: 4.7% total binder content.	*Test Track Study:* Phase VII (2018-2021) NCAT Test Track Study
	September 2011 to August 2012	RAP/RAS Mix Design, performance evaluation system, Project-specific service conditions, Overlay Test (OT), HWTT, dynamic modulus (not a good indicator for cracking resistance), soft and modified binder.	*Project*: Balanced RAP/RAS Mix Design and Performance Evaluation System for Project-Specific Service Conditions
	August 2022	Different BMD approaches, experimental evaluation, overlay tester, HWTT, gradation adjustment	*Project*: Develop Guidelines and Design Program for Hot-Mix Asphalts Containing RAP, RAS, and Other Additives through a Balanced Mix-Design Process
	October 2024 to August 2027	Defensible and practical skid resistance laboratory assessment, long-term skid resistance, mix type, gradation, fines quality.	*Project*: Incorporating Lab Skid Measurements into the Balanced Mix Design Process
	March 2024	Cracking and rutting distresses, Automated Testing System with Zero Intervention (AMAZE) with robotic arm; IDEAL CT, IDEAL-RT, IDT strength test.	*Project*: Asphalt Mixture Automated Testing System with Zero Intervention (AMAZE)
	September 2024 to August 2027	Durable RAP mixes, minimum virgin binder content, overlay test, IDEAL-CT, statistically sound laboratory experimental design, correlation between field performance and laboratory mix cracking properties.	*Project*: Evaluating Minimum Virgin Binder Contents for Durable Recycled Asphalt Pavement (RAP) Mixes
	September 2021 to April 2025	Lab-molded density, balancing high lab-molded density values at plant production, field performance, QC/QA, acceptable range of lab-molded densities for laboratory mix design.	*Project*: Establish Performance-Based Acceptable Lab-Molded Density Range for Mix Design and QC/QA

BMD-Related Studies by States

BMD implementation across the United States encompasses a broad spectrum of interrelated research themes that collectively advance performance-based design practices. Core topics consistently identified include (1) performance-based testing and (2) specification verification and correlation, which form the foundation for linking laboratory results to field performance and ensuring alignment with agency requirements. A critical objective is to establish (3) reliable performance-based criteria that can be effectively adopted in practice as metrics for both mix design and QA/QC. Given that significant variability may occur during testing and production, (4) variability and sensitivity analyses warrant detailed investigation. To accurately assess long-term pavement performance, (5) mixture aging protocols are essential to realistically simulate field conditions.

While volumetric parameters remain integral to mix design and quality control, their role is evolving toward a more performance-centered approach. Therefore, (6) volumetric and constituent properties and (7) aggregate characteristics continue to play important roles in research and practice, while (8) gradual relaxation of traditional volumetric requirements reflects the ongoing transition from empirical design toward performance-based specifications. Additional areas of importance include (9) QA/QC practices, which are vital for ensuring consistency and reliability across production and testing environments. (10) Benchmarking further supports the development of reproducible and comparable testing frameworks across existing mix designs, aging protocols, and different BMD approaches.

(11) RAP/RAS incorporation and (12) modifiers and additives emphasize sustainability and innovation within asphalt mixture design. Finally, (13) BMD field trials, validation through performance monitoring, and the development of a (14) standardized BMD framework with procedural guidelines, including integration into pavement design practices, illustrate the evolution of BMD from conceptual development to broad implementation.

Many BMD-related studies have been conducted on diverse mixture categories, such as surface, base, dense-graded (thin lift), OGFC, SMA, Asphalt Fine Aggregate Matrix (FAM), and High-Performance Thin Overlay (HPTO) mixes, depending on each state's definition and application. The primary categories and corresponding subtopics of these state-level studies are summarized in Table 6**,** which provides a detailed insight into the core topics mentioned above.

Table 6. Summary of completed and ongoing state-based studies and projects

Primary Categories	Subsets of Detailed Topics	State Studies and Time
Performance-based tests Studies: 85 States: 35	Performance-based tests: – Cracking (thermal cracking, low temp., and intermediate temp.) – Rutting – Moisture susceptibility – Friction – Surrogate tests/ alternative tests/ rapid tests Performance-based tests specification: – Preliminary threshold criteria – Property-temperature relationships – Performance Space Diagram – Surrogate tests indices – Performance thresholds refinement	– **VA** (May 2021, Jan. 2023, Mar. 2023, Jun. 2023, Variability Jun. 2023, Jun. 2024, Jan. 2025, Sept. 2025, Jul. 2026) – **LA** (Sept. 2014, Jul. 2019, Mar. 2021, Mar. 2025) – **GA** (Apr. 2022) – **AL** (Apr. 2020) – **AR** (Dec. 2022, Aug. 2023) – **NC** (Dec. 2024, Jul. 2024) – **OK** (Aug. 2019, 2021, Jun. 2024 (test), Aug. 2025) – **TN** (Aug. 2026) – **TX** (2018 to 2021, Aug. 2022, Aug. 2027, Aug. 2027 [RAP]) – **VT** (May 2023, Oct. 2024) – **KS** (Jan. 2025) – **CA** (Aug. 2018, Mar. 2021, Sept. 2026, Oct. 2020) – **IN** (Apr. 2020) – **AZ** (Oct. 2025) – **ID** (May 2023, May 2021, Jun. 2018, Dec. 2024) – **IL** (Aug. 2019, 2018 to 2021) – **ME** (2022) – **MD** (Dec. 2021) – **MN** (Jun. 2018, Jun. 2019, Aug. 2024, Jan. 2021, Mar. 2023) – **MO** (Dec. 2024, Jun. 2020, Jul. 2022, May 24) – **NE** (Sept. 2020, May 2025, May 2026, Nov. 2024) – **NV** (Dec. 2021, Aug. 2024) – **NH** (Jun. 2019) – **NJ** (Sept. 2015) – **NM** (Apr. 2019, Feb. 2025) – **NY** (Mar. 2021, Nov. 2022) – **ND** (2022) – **OH** (Nov. 2021, Sept. 2023, Jul. 2028) – **OR** (Nov. 2020, Aug. 2021) – **PA** (Jul. 2023) – **UT** (Dec. 2017, Mar. 2019, Sept. 2020, Jul. 2021, Oct. 2019, Jul. 2022) – **WA** (Dec. 2020) – **WI** (Sept. 2018, Mar. 2021) – **NCHRP** 09-57

Specification verification & correlation Studies: 17 States: 10	– Correlation between performance test results and volumetric parameters – Field performance data correlations – Lab-to-field aging correlation – Field core testing	– **TX** (Aug. 2027 [RAP]) – **OK** (Aug. 2025) – **LA** (Sept. 2014, Mar. 2021, Mar. 2025) – **VA** (May 2021, Jun. 2024) – **AL** (2022-?, Apr. 2020) – **CA** (Oct. 2020) – **MN** (Nov. 2023) – **MO** (Dec. 2024, Jun. 2020) – **NE** (May 2025) – **WI** (May 2024) – **NCHRP** 09-57 – **NCHRP** 9-48
Volumetrics & constituents Studies: 13 States: 10	– Binder source and content – Asphalt content – Corrected Optimum Asphalt Content – Gradation – Gradation and volumetric adjustment – Optimum binder content – Lab-molded density – Balanced Mix Design Gyrations Index—volumetrics relationships	– **VA** (Mar. 2026) – **LA** (Mar. 2025) – **NC** (Dec. 2024) – **TX** (2018 to 2021, Aug. 2027, Apr. 2025) – **VT** (2022) – **MD** (Dec. 2021) – **MN** (Mar. 2023) – **MO** (Aug. 2024, May 2024) – **OH** (Nov. 2021) – **WI** (Sept. 2018)
Aggregate Studies: 4 States: 4	– Relatively soft aggregate – Max. amount of sandstone aggregates – Alternative local aggregate – Fines quality – Aggregate and binder compatibility	– **TX** (Aug. 2027) – **AR** (Aug. 2023) – **IL** (2020 to 2023) – **MO** (May 2024)
Relaxation of volumetric requirements Studies: 4 States: 4	– Withdrawing the regressed air voids design requirement, – Gradation adjustment – Current tolerance limits for binder content – In-place density on performance	– **TX** (Aug. 2022) – **VA** (Variability Jun. 2023) – **MO** (Aug. 2024) – **WI** (Sept. 2018)
Aging Studies: 25 States: 13	– Reheating effects and isolation – Short-term and long-term aging – Scaling factor – Effects of silo storage – Lab-to-field aging correlation – Aging conditions from plant to lay down and field cores	– **VA** (Jan. 2025, Mar. 2026) – **LA** (Jun. 2024, Mar. 2025) – **TN** (Aug. 2026) – **NC** (Dec. 2024) – **AR** (Dec. 2022) – **IL** (Aug. 2019, 2018 to 2021) – **MN** (Jan. 2021, Nov. 2023, Apr. 2025) – **MO** (May 2022) – **NE** (May 2025, Jul. 2024, Nov. 2024) – **NH** (Jun. 2019) – **OR** (Nov. 2020) – **UT** (Dec. 2017, Jul. 2021, UTC Jul. 2022) – **WA** (Dec. 2020)

		– **NCHRP** 09-70, **NCHRP** 09-54, **NCHRP** 9-52
QA/QC Studies: 21 States: 13	– Plant-produced mixtures – Mix design verification – Performance-related QA/QC – Acceptance – QA testing program – Non-destructive QA method (Ultrasonic Pulse Velocity) – Balancing high lab-molded density values at plant production – Coherent BMD/QA/QC framework	– **VA** (Mar. 2023, Jun. 2023, Jan. 2025, Sept. 2025) – **LA** (Sept. 2014, Jun. 2024, Mar. 2025) – **AL** (2024-?) – **AR** (Aug. 2023) – **NC** (Dec. 2024, Jul. 2024) – **TX** (Apr. 2025) – **KS** (Jan. 2025) – **CA** (Oct. 2020) – **IN** (Apr. 2020) – **MN** (Jan. 2021) – **NJ** (Sept. 2015) – **OH** (Nov. 2021, Jul. 2028) – **WI** (May 2024) – **NCHRP** 09-70
Variability & sensitivity Studies: 30 States: 16	– Production variation between sublots, sources, and mix batches – PMLC, LMLC, PMFC, FMLC, FMFC, entity, producer, and district variation – Within-lab and interlaboratory study – Laboratory repeatability – Analysis of Variance (ANOVA) – Operating parameters – Key variability statistics	– **VA** (Mar. 2026, Variability Jun. 2023) – **LA** (Mar. 2021) – **AL** (2022-?, Apr. 2020) – **OK** (Aug. 2025) – **NC** (Dec. 2024) – **VT** (2022, Nov. 2023, 2024) – **CA** (Sept. 2026, Mar. 2021) – **IN** (Apr. 2020) – **IL** (Aug. 2019, 2018 to 2021) – **MN** (Nov. 2023, Mar. 2023) – **MO** (Dec. 2024, May 2022, May 2022) – **NE** (May 2025) – **ND** (2022) – **UT** (Dec. 2017, Jul. 2022, UTC Jul. 2022, Feb. 2023) – **WA** (Dec. 2020) – **WI** (May 2024) – **NCHRP** 09-72, 09-57
Benchmarking Studies: 9 States: 7	– Performance tests – Volumetric benchmarks – Different aging protocols – Different BMD approaches – BMD vs. Superpave volumetric approach	– **OK** (Aug. 2025) – **TN** (Aug. 2026) – **TX** (2018 to 2021, Aug. 2022) – **IL** (Aug. 2019) – **ME** (2022) – **OR** (Apr. 2025) – **WI** (Mar. 2021, May 2024)
RAP/RAS Studies: 18 States: 13	– High RAP content (50% or 70%) – Cold-recycling processes – Minimum virgin binder content	– **VA** (Mar. 2023, RAP Dec. 2023) – **LA** (Jul. 2019) – **GA** (Apr. 2022) – **OK** (2021) – **TX** (Aug. 2012, Aug. 2027 [RAP])

		– **KS** (Jan. 2025) – **CA** (Sept. 2026, Mar. 2021) – **ID** (May 2021, May 2023, Dec. 2024) – **MN** (Apr. 2025) – **NE** (Nov. 2024) – **NM** (Feb. 2025) – **PA** (Jul. 2023) – **WA** (Dec. 2020)
Modifications & additives Studies: 13 States: 8	– SBS modified, high polymer modified – Fiber-reinforced materials – Recycling agent, recycling additives, rejuvenating asphalt emulsions – Tall oil and waste vegetable oil – Softener-type modifiers, bio-based modifiers – Recycled plastic, GTR – Triglycerides and Fatty Acids (TF) – Antioxidants, zinc diethyldithiocarbamate (ZnDEC)	– **VA** (RAP Dec. 2023, Jul. 2026) – **OK** (2021) – **CA** (Mar. 2021) – **IN** (Apr. 2020) – **ID** (May 2023, Dec. 2024, 2018 to 2021) – **MN** (Aug. 2024, Apr. 2025) – **MO** (Dec. 2024, Jul. 2022) – **NE** (Nov. 2024)
BMD field trial & validation performance monitoring Studies: 20 States: 10	– Trials – Pilot projects – Shadow projects – Test track – Field validation of BMD test criteria – Field performance relationship – Field vs. Laboratory Performance – Calibration with 20-year projected distresses – PMS	– **VA** (Jun. 2021, Mar. 2023, Jun. 2023, Dec. 2023, Jun. 2025, Mar. 2026) – **AL** (2022-?, 2018 to 2021) – **OK** (Aug. 2025) – **NC** (Dec. 2024) – **OK** (2021, Jun. 2024 [field]) – **TX** (2018 to 2021) – **KS** (Jan. 2025) – **CA** (Mar. 2021) – **MN** (Nov. 2023, Apr. 2025) – **OH** (Nov. 2021) – **UT** (Jul. 2021, UTC Jul. 2022) – **NCHRP** 09-57
BMD framework & procedures Studies: 21 States: 13	– Case studies/literature review – White paper – Roadmap – Training and certification – BMD framework and procedures – Survey on DOTs implementation – Coherent BMD/QA/QC framework – Pay assessment schedules – Cost-effective analysis	– **VA** (May. 2021, Sept. 2025, Jul. 2026) – **LA** (Sept. 2014, Mar. 2021, Mar. 2025) – **AL** (2024-?) – **OK** (Aug. 2025) – **NC** (Jul. 2024) – **TX** (Mar. 2021) – **CA** (Mar. 2021) – **IL** (Mar. 2021) – **ME** (Mar. 2023) – **MO** (May 2022) – **NE** (May 2025) – **NV** (Mar. 2022, Aug. 2024) – **NJ** (Mar. 2021) – **NCHRP** 09-71, **NCHRP** 10-107, **NCHRP** 20-07

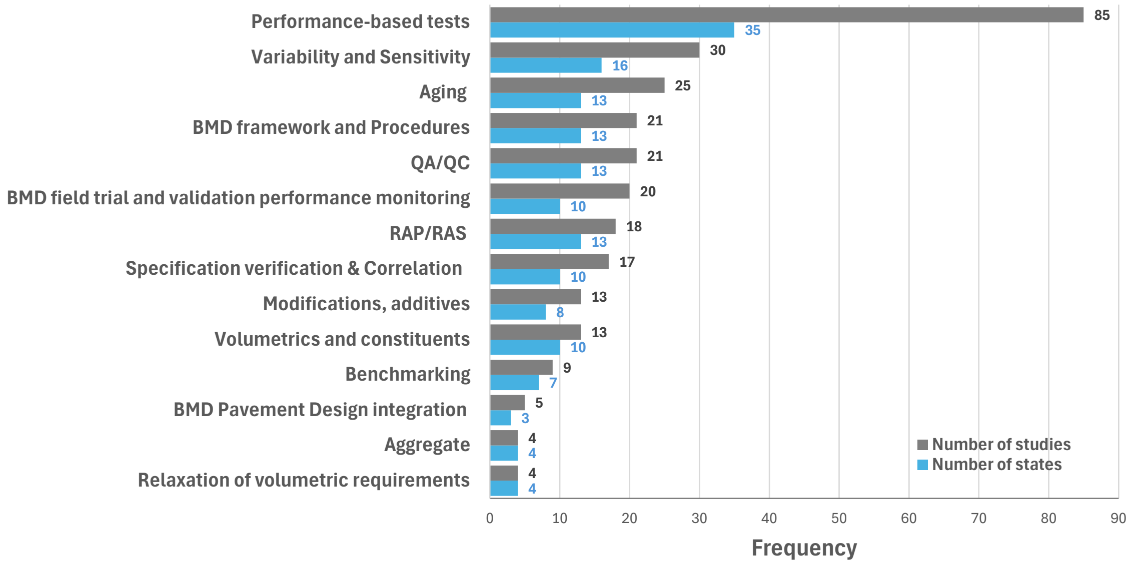
BMD pavement design integration Studies: 5 States: 3	– Mechanistic-Empirical (ME) design/ FlexPAVE – Integration of mix design and structural design – Cost-effective analysis	– **VA** (Jun. 2024) – **CA** (Aug. 2018, Oct. 2020, Sept. 2026) – **MO** (May 2024)

Note: SASHTO member states are noted in red text.

Discussion of State-Based BMD Research Landscape

Figure 9 illustrates the frequency and distribution of major research topics (1) through (14) associated with BMD implementation across state and national studies. The gray bars represent the number of studies addressing each topic, while the blue bars indicate the number of states in which these topics have been explored.

Figure 9. Summary of research topics of state-based BMD-related studies



As expected, performance-based tests have been a central focus of research, appearing in 85 studies across 35 states, underscoring their central role in linking mixture design to pavement performance. These studies span IDEAL-CT/I-FIT/SCB/DCT and HWTT/APA/IDEAL-RT tests and dominate the evidence base for BMD test selection and thresholding. Surrogate/rapid performance tests are essential subsets of this category, reflecting the need for fast, effective test protocols. Many states are repeating similar validation/calibration exercises (e.g., IDEAL-CT/I-FIT/SCB and HWTT), often with convergent objectives. This is productive locally but creates duplication nationally. Moreover, given safety/function priorities, coupling BMD with surface functional metrics (e.g., friction, texture, and micro- and macro-texture retention over time) has been studied only by Texas (August 2027) and Missouri (May 2024), leaving a clear gap.

Extensive research has also addressed variability and sensitivity (30 studies across 16 states), focusing on within- and between-laboratory precision, production variability, and field-to-lab consistency. This topic remains a high priority due to persistent concerns regarding test repeatability and mix performance consistency. Although numerous studies have quantified variability using statistical approaches such as ANOVA-based reproducibility, translating these results into enforceable QA/QC acceptance criteria remains a major challenge. Consequently, despite the progress in characterizing variability, the gap between statistical evaluation and practical specification implementation needs to be investigated further.

Aging protocols represent another major research focus (25 studies across 13 states), primarily focusing on short- and long-term conditioning procedures (e.g., AASHTO R 30, NCHRP 09-54 and 09-70). Many studies (e.g., Louisiana, Virginia, Minnesota, Nebraska, and NCHRP 09-54) have explored correlations between laboratory and field aging. However, comprehensive investigations into long-term aging remain limited. The development of a unified, field-calibrated long-term aging (LTA) protocol tailored to climate zones and mix types, along with practical QA aging or surrogates that capture true or simulated LTA effects within feasible timeframes, remains one of the most pressing research needs.

Topics such as BMD framework development, QA/QC integration, and field validation (each with 20 to 21 studies) demonstrate significant progress in institutionalizing BMD within agency practice. These studies have yielded white papers, roadmaps, and pilot projects. The next critical step is to translate conceptual frameworks into enforceable specifications, supported by pay schedules, training, and certification programs. Emerging but still significant areas include RAP/RAS incorporation, modifiers and additives, volumetric and constituent considerations, and benchmarking, which contribute to refining mixture optimization and cross-agency comparability.

Field trials and performance monitoring, specification verification, and correlation are mid-tier topics that demonstrate ongoing efforts to validate laboratory findings in practical applications to obtain verified, field-proven, and workable specifications. Topics such as BMD pavement design integration, aggregate characterization, and the relaxation of volumetric requirements appear less frequently but represent evolving frontiers as agencies progress toward full performance-based specifications. Relaxation of volumetric requirements is one of the primary objectives of BMD implementation. The new AASHTO standard defining the tiers of BMD minimizes detailed constituent and volumetric requirements, with primary reliance instead on performance-based material and design optimization and mechanical testing to validate mixture performance. A structured pathway for progressive volumetric relaxation would help agencies move confidently toward performance governance. However, until essential topics, such as performance specifications, specification validation, appropriate aging protocols, and QA/QC procedures, are adequately studied and established, increased flexibility in constituent selection and volumetric requirements should not be adopted without a solid technical foundation. The same principle applies to expanded use of high RAP/RAS contents and the adoption of innovative modifiers and additives intended to enhance performance and sustainability.

Recommendations Based on Current State and National Studies

The synthesis of existing state and national studies highlights both strong progress and notable redundancies across multiple BMD research themes, despite asphalt mixture design and highly localized practices. To move from fragmented, state-specific developments toward a consistent and implementable regional framework, the following strategic recommendations are proposed.

Consolidate highly focused research areas into consensus guidance

Substantial overlap exists in cracking (IDEAL-CT) and rutting (HWTT, IDEAL-RT) performance tests, variability studies, and BMD framework development. These efforts should be consolidated into national consensus guidance that focuses on harmonized test protocols and interpretation criteria. Establishing national calibration curves and reference distributions for the IDEAL-CT, HWTT, and similar performance tests would enable the consistent application of thresholds across states while maintaining local flexibility.

Implement acceptance criteria with variability considerations

Given the considerable volume of work on test repeatability and inter-laboratory precision, the next step is to translate these findings into practice. Agencies should develop coefficient-of-variation (COV)-based acceptance limits, risk-balanced pay schedules, and well-defined laboratory and field surveillance frequencies. These measures would strengthen quality assurance and provide defensible, performance-linked specification control.

Develop and publish a practical long-term aging (LTA) matrix

Aging remains a critical research gap. A standardized climate- and mix-specific LTA matrix should be developed to bridge the relationships of short-term aging (STA), long-term aging (LTA), and field aging conditions. The matrix should include time-feasible QA surrogates and a predicted performance after LTA that accurately represent field aging behavior, allowing agencies to evaluate mixture performance within practical laboratory timeframes.

Advance BMD and ME/FlexPAVE integration pilots

To fully integrate performance-based design into pavement engineering practice, select pilot states with strong field monitoring capabilities should conduct end-to-end ME/FlexPAVE demonstration projects. These pilots should link laboratory mix performance thresholds to structural design parameters, generate calibrated transfer functions, and feedback performance data through pavement management systems (PMS) to refine design criteria.

Incorporate a friction and surface functionality metric

Given the limited research on surface functional metrics, future BMD implementation could explicitly include a friction and texture performance track, addressing both initial friction and long-term retention that is largely influenced by the quality and mineral properties of aggregate. This is particularly critical for thin overlays, OGFC, and SMA mixtures, in which surface functionality directly affects safety and user satisfaction.

Variability-aware and practically feasible QA/QC acceptance

Numerous studies have quantified within- and between-laboratory variability and production variability, yet these findings have not been fully translated into specification practice. In practical implementation, QA/QC testing is influenced by factors such as specimen conditioning requirements, turnaround time, testing frequency, available testing capacity, and staffing resources. The QA/QC specifications may be either consistent with or distinct from those used during mix design, depending on agency practice and operational feasibility. Recognizing these operational constraints is essential to ensure that BMD-based QA/QC procedures remain both technically sound and logistically achievable.

Establish decision frameworks for RAP/RAS and modifiers

To support a performance-driven economy, sustainability, and innovation, agencies should establish standardized decision frameworks linking recycled material contents (e.g., RAP and

RAS) and modifier or additive selections to measurable performance thresholds and validated field outcomes. Incorporating life-cycle cost analysis (LCCA) within this framework would further ensure that environmental and economic benefits are realized without compromising long-term durability. However, without a robust foundation of verified performance specifications and rigorous field validation, such an implementation would remain premature and insufficiently supported.

Stepwise volumetric relaxation framework

As agencies transition toward performance governance, a stepwise volumetric relaxation strategy is needed. This framework should define relaxation limits based on demonstrated performance, aggregate quality envelopes, and robust QA guardrails. Progressive adoption of volumetric flexibility should occur only after core topics, such as performance test specifications, validated aging protocols, and QA/QC procedures, are established to ensure reliability and consistency.

In summary, coordinated regional and national actions are essential to streamline ongoing research, reduce redundancy, and close existing implementation gaps. By emphasizing harmonization, statistical quality assurance, practical feasibility, functional performance, and mechanistic integration, SASHTO agencies can advance toward a fully performance-based, sustainable, and resilient pavement design and management system.

Summary and Analysis of First Round Survey

General Overview of First Round Survey

This survey was a core component of the synthesis study. The purpose of the survey was to capture the current status, practices, challenges, and opportunities related to the implementation of BMD across state transportation agencies in 2025. The survey feedback from 36 state DOTs reveals a highly varied but steadily progressing landscape of BMD implementation. It was structured to gather detailed information on agency research efforts, available data resources, BMD framework and approaches, performance test adoption, aging and conditioning protocols, lag and dwell time requirements, adjustments to volumetric specifications, key gaps, and challenges. By combining multiple-choice questions with open-ended responses, the survey is designed to provide both quantitative data and qualitative insights, offering a robust basis for benchmarking BMD adoption nationwide. The detailed first round survey questionnaire is included in Appendix A3.

The following state transportation agencies provided valuable input to the first round survey: Alaska, Alabama, Arizona, Arkansas, Colorado, Connecticut, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Minnesota, Mississippi, Missouri, Nebraska, New Jersey, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Utah, Vermont, Virginia, West Virginia, and Wyoming.

Section 1. Research Efforts and Related Research Projects (Completed or Ongoing)

Figure 10 illustrates the overall level of involvement of state DOTs in BMD-related activities, in response to the multiple-choice question, *"Has your agency conducted, or are you currently conducting, any shade, pilot, or research projects related to Balanced Mix Design (BMD)?"* The results show that a majority of states have either previously conducted or are currently conducting BMD projects, reflecting widespread interest and growing momentum, while a smaller number remain in the exploratory or planning phase.

Figure 11 categorizes the primary technical focuses addressed in ongoing BMD projects. Figure 12 presents the future research needs identified by state DOTs as top priorities for advancing BMD. The distribution of responses shows that performance test evaluation and field correlation are the most common areas of emphasis, underscoring the current need to ensure that laboratory results reliably predict field performance. In terms of both current and future primary technical topics that interest DOT agents, those related to quality assurance/quality control (QA/QC) are not among the top-ranked choices shown as Figure 11 and Figure 12. The reason could be either that it is still too early in the implementation stage in certain states or that it is very time-consuming for certain performance tests, such as HWTT and LTA for cracking, to be fully evaluated in the QA/QC process. Therefore, as observed in the following feedback, fast, practical, and effective surrogate performance tests such as IDEAL-RT are desired to replace time-consuming tests during mix design.

Figure 10. Responses to the multiple-choice question "Has your agency conducted, or are you currently conducting, any shade, pilot, or research projects related to Balanced Mix Design (BMD)?"

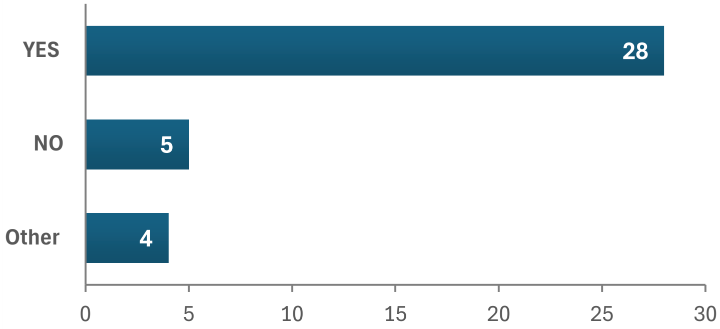


Figure 11. Emphasis topics of BMD-related shade, pilot, or research projects

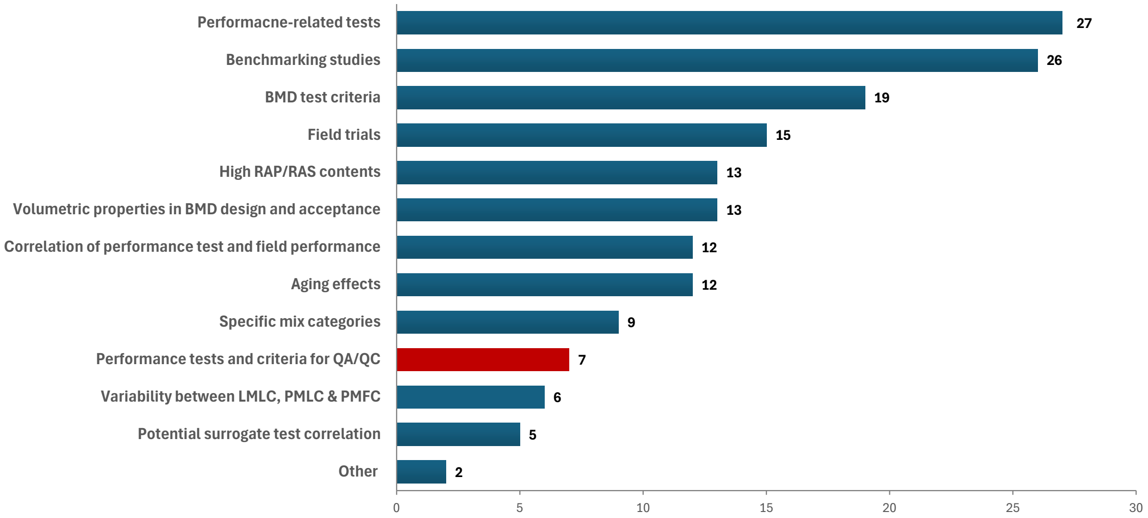


Figure 12. Prioritized future BMD-related research topics ranked by DOT agents

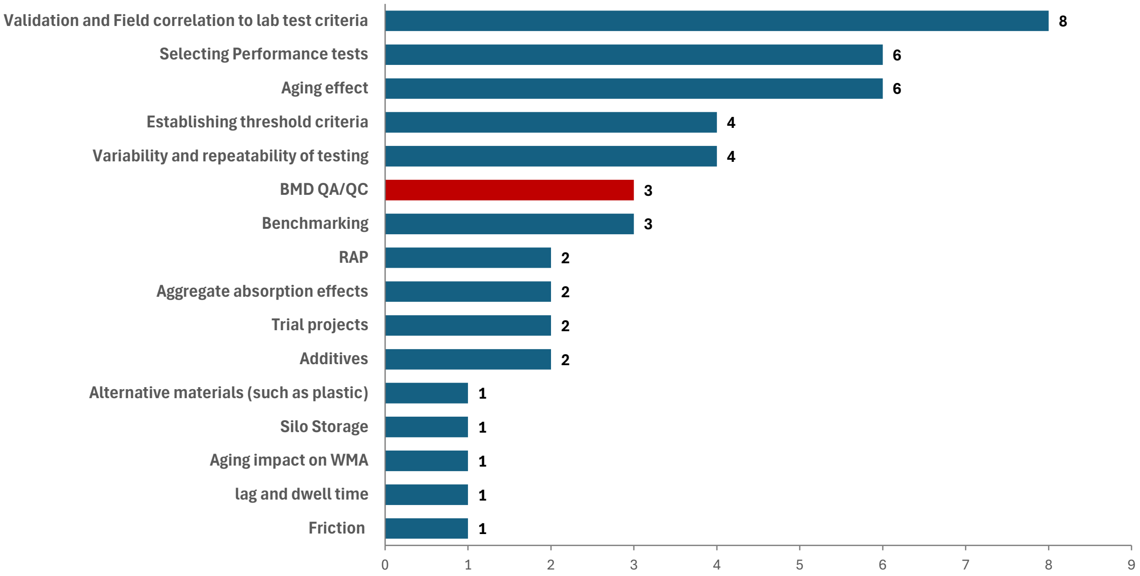


Table 7 summarizes the specific BMD-related topics DOT agencies prioritized for future research. Five major categories of emphasis are observed: field trial projects and field validation; performance testing focus; aging and durability studies; RAP, recycled materials, and additives; and precision and repeatability.

Table 7. Specific research topics DOT agencies prioritized for future BMD-related research

State	What specific BMD-related research topics does your agency prioritize for further research?
Nebraska	None at this time. Just gathering field production samples and testing with CT and RT to gather more data for benchmarking.
Ohio	Real goal is to get more BMD Trial Projects down throughout the state. Currently using my staff to do this so we're limited on the number we can do per year. Hopefully if we do enough then we'll get a great field correlation to lab test criteria.
Indiana	None at this time.
Missouri	BMD Variability, SIP Parameter from Hamburg, Absorptive Aggregate effects.
Utah	We're looking to investigate further the variability and impact of RAP in our mixtures, the impacts of warm mix asphalt on pavement aging.
South Dakota	Correlation to field performance.
New Jersey	Use of quicker performance testing that can be used during production and for quality control at the plant, use of testing that correlates to long-term performance of pavement, accuracy, and repeatability of testing.
Colorado	Lime vs liquid antistrip.
Virginia	COV and D2S for precision and bias.

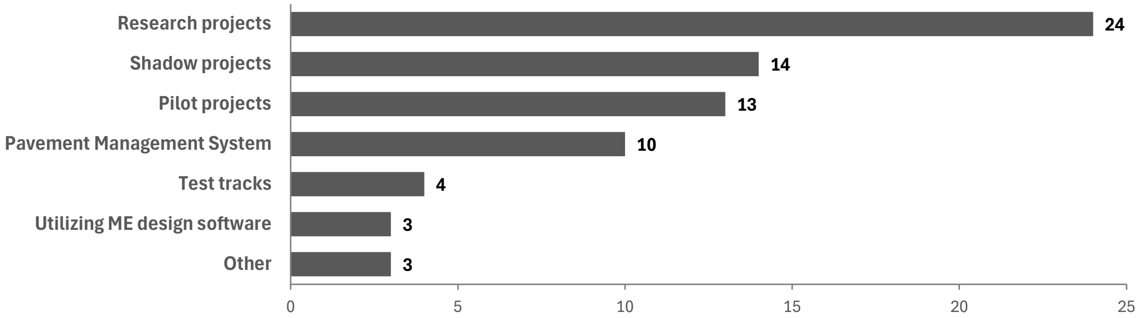
Vermont	Validation of preliminary BMD thresholds and ensuring the criteria align with actual field performance is a gap that we're looking to have completed within the next 5 years. Long-term oven aging (LTOA) of loose-mix samples is also high on the priority list.
Georgia	We have no plan for related research. We are still collecting IDEAL-CT results for consideration of establishing specified tolerances.
Arkansas	Accelerated aging, friction.
Oklahoma	Additives, aging, silo storage, long-term performance.
North Carolina	Ideal RT.
Mississippi	Slecting the best performance tests for us.
Kansas	Aging, lag and dwell time.
New Mexico	Establishing threshold criteria for CT and RT.
Tennessee	Utilizing BMD in QA/QC.
Minnesota	Appropriate cracking test, performance tests to field performance.
Oregon	High RAP content, field trials.
North Dakota	Aging and how different aggregates are affected (example: high absorption in shales).
Illinois	To be determined.
Hawaii	Current plan is to use BMD to allow use of alternative materials (such as plastic).
South Carolina	We are collecting IDEAL-CT data during the mix design process.
Florida	Benchmarking of crack-resistance tests. Variability between plant sampling vs from the paver auger.
Alabama	Benchmarked mixes 2021-2023, validation section placed 2024 with another to be placed spring 2026.
Louisiana	Research dating back to 2002. Various duration of projects. Future research: Aging relationships, surrogate tests, production testing.

Summary	
Topics	**States**
Field trial projects & field validation	– Ohio (trial projects, field correlation), – Vermont (validation of thresholds, long-term oven aging) – South Dakota (field correlation) – Minnesota (field performance) – Oregon (field trials) – Alabama (validation section)
Performance testing focus	– Missouri (variability, Hamburg SIP, absorptive aggregates) – New Jersey (quick tests for QC, repeatability, long-term correlation) – North Carolina (IDEAL-RT) – Mississippi (best performance tests) – Tennessee (QA/QC) – Florida (benchmarking) – Alabama (benchmarking) – Louisiana (surrogate tests, production testing)
Aging studies	– Kansas (aging, lag/dwell time) – Arkansas (accelerated aging) – Oklahoma (aging, long-term storage, additives) – North Dakota (aging with high-absorption aggregates) – Utah (warm mix and RAP impact on aging)

	– Vermont (long-term oven aging) – Louisiana (aging relationships)
RAP, recycled materials, & additives	– Colorado (lime vs. liquid antistrip) – Oklahoma (additives, silo storage) – Hawaii (alternative materials like plastic) – Oregon (high RAP content) – Utah (RAP variability)
Precision & repeatability	– Virginia (COV, D2S for bias/precision) – New Jersey (accuracy, repeatability) – Florida (variability between plant sampling vs from the paver auger)

Since performance testing (e.g., IDEAL-CT, HWTT, APA, SCB) requires adequate reference data to validate performance thresholds, the survey asked DOTs for their available data resources. This information helps identify the evidence base agencies can use to validate performance tests and criteria, highlight existing gaps, and assess the potential of regional or national implementation strategies for BMD and performance specifications. The summarized feedback is presented in Figure 13.

Figure 13. Available data resource for your state DOT for performance test validation, performance criteria, and specifications



Section 2. BMD Framework

Scope of BMD Implementation

BMD implementation across state DOTs remains highly diverse, reflecting varying levels of experience, resources, and strategic priorities. Table 8 summarizes the feedback by DOT agents for the scope of BMD implementation.

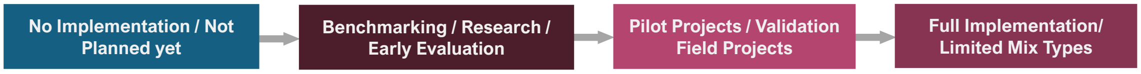
Table 8. Feedback from DOT agents regarding the scope of BMD implementation

State	What is the scope of BMD implementation in your state?
Nebraska	We do not plan to implement for QA/QC. We will use it to support our current system and help with our specs and designs.
Ohio	Not sure what is being asked. The ultimate goal is to apply this to everything and be able to reduce mix types (we currently utilize Marshall and SuperPave) and increase RAP responsibility.
Indiana	None. Based on our interlaboratory study, the inconsistency and variability between labs with the same material is of great concern.
Missouri	Pilot Projects on SuperPave mixtures.
Utah	We are using what we call HiMod high-density asphalt all over our state. This mix uses a PG 76-34 highly modified binder with the mix designed at 1% voids, 50 gyrations (near zero voids at 75 gyrations). The high binder content mixture can be placed in thick or thin layers and has proven to produce a high-performance pavement at a cheaper cost than SMA. We are now also allowing up to 15% RAP in our surface courses. Previously, RAP was only allowed in the lower HMA layers.
South Dakota	Specific mix category (mostly mainline mixes).
New Jersey	Use is for specific mixes on medium and high traffic level projects.
Wyoming	No implementation.
Colorado	Pilot Projects.
Virginia	Surface mix for 10,000 and above ADT.
Vermont	All projects at this time.
Georgia	We have implemented a number of performance tests related to BMD in conjunction with the COAC process, but haven't officially called it BMD.
West Virginia	We are not yet to this point.
Arkansas	Wanted to allow contractors the option to be creative.
Oklahoma	All projects.
North Carolina	Surface mixes only at this time.
Mississippi	Still only benchmarking mix designs.
Kansas	We have not set a date for implementation. We are really struggling with how much to account for short-term aging during production without causing more variability in test results (between parties testing and between projects).
Tennessee	Current focus has been on our dense-graded surface mixture for benchmarking and validation test sections.
Minnesota	Benchmarking.
Oregon	Currently pilot projects.
North Dakota	As of now unsure. Hoping to have on all, but unsure on starting point. More research needed.
Illinois	All Projects–implemented.
Hawaii	Pilot.
Florida	At this point, FDOT is not prioritizing the implementation of BMD.
Alabama	Pilot projects.
Louisiana	All wearing and binder course mixtures.
N/A / No feedback provided Alaska, Arizona, Maine, New Mexico, South Carolina, Connecticut, Rhode Island, Kentucky, Idaho	

Scope of BMD Adoption

According to the feedback of DOT agents, a summary of BMD implementation scope across states shows that states are at very different stages of BMD adoption; see Figure 14.

Figure 14. Different stages of BMD implementation across states



- **No Implementation / Not Planned Yet**
  - West Virginia, Florida, Nebraska, Indiana, Wyoming, Kansas (uncertain), North Dakota (unsure), and New Mexico. Reasons include concerns over variability, lack of clear guidance, or no plans for QA/QC use.
- **Benchmarking / Research / Early Evaluation**
  - Mississippi, Minnesota, Indiana, and Kansas. Activities primarily involve benchmarking studies, validation sections, and inter-lab variability studies.
- **Pilot Projects / Validation Field Projects**
  - Hawaii (pilot), Alabama (pilot), Tennessee (validation test sections), Missouri, Colorado, Oregon, and South Dakota.
- **Limited Mix Types / Full Implementation**
  - Oklahoma (all projects), Louisiana (all wearing and binder course mixtures), Virginia (all surface mixes), North Carolina (surface mixes), Arkansas (surface mixes only, 1/2" and 3/8' mixes), Illinois (all projects, fully implemented), New Jersey (medium/high traffic mixes), and Vermont (all projects). These states are applying BMD on selected mix types, traffic levels, or nearly all projects.
- **Using Other Approaches or Modified Practices**
  - Utah stands out with its use of HiMod high-density asphalt system (PG 76-34, very low voids, up to 15% RAP), offering a cheaper alternative to SMA. Georgia integrates performance tests into the COAC process without formally referring to it as BMD.

BMD Approaches

The scope of BMD implementation across U.S. states ranges widely from no immediate plans (e.g., Nebraska, Wyoming) to full statewide implementation (e.g., Illinois, Virginia, Oklahoma). A common entry point has been pilot projects or benchmarking studies, which allow agencies to build confidence before broader implementation. Key challenges noted include test result variability, treatment of aging protocols, and integration into QA/QC practices. At the same time, some states are pursuing innovative approaches, such as Utah's HiMod high-density asphalt and Georgia's incorporation of performance testing within the COAC process, demonstrating flexibility in adapting BMD principles to local contexts.

DOT feedback shows a mixed landscape in the adoption of BMD approaches:

- **Still Evaluating / TBD**
  - Twelve states remain in the evaluation stage without committing to a specific approach (Nebraska, Indiana, Missouri, Wyoming, Vermont [partial], Mississippi, Tennessee, Minnesota, Oregon, North Dakota, Hawaii, and Florida).
- **Approach A**
  - Eight states have adopted this approach (Utah, South Dakota, New Jersey, Vermont, Alaska (partial), West Virginia, Kansas, Illinois). It is widely recognized as the most common starting point for BMD implementation and is often tied to verifying volumetric designs with one or two performance tests. Illinois is using Approach A and removing VFA requirements. Vermont indicated that Approach A is currently in use, but the agency would prefer to transition to Approach C or D long term.
- **Approach B**
  - Seven states have adopted this approach (Utah, New Jersey, Colorado, Virginia, Oklahoma, New Mexico, and Alabama).
- **Approach C**
  - Five states have adopted this approach (Ohio [pilot], Colorado, Georgia, Maine, Tennessee [anticipated]). This is typically tied to higher RAP usage or specification refinements. Georgia is still evaluating if additional performance tests and/or specification changes are needed.
- **Approach D**
  - Three states have adopted this approach (Arkansas, North Carolina [full performance-based design], Ohio [long-term plan for high RAP projects]).

- **Other / Hybrid**
  - — Three states report hybrid practices or deviations. Utah and Louisiana use both A and B, and Ohio notes that its BMD implementation starts with pilot projects using Approach A or B and eventually transitions to Approach D.

Most state DOTs are not committing to a single BMD approach but are instead exploring multiple pathways and treating the approaches as stages of implementation rather than fixed endpoints. Nearly half of the states remain in the "Still Evaluating / TBD" phase, reflecting caution and the need for additional benchmarking and pilot projects before formal adoption, which is consistent with the observations from the literature mentioned in the previous section. When applied, approaches are often limited to specific contexts, such as certain mix types, higher RAP contents, or high-traffic surface courses, rather than being used universally. Several states explicitly describe BMD as a tiered or phased process, beginning with Approach A or B for pilots and gradually moving toward Approach C or D; for example, Vermont uses this approach as confidence in performance tests and variability control increases. This aligns with the recent AASHTO shift in terminology from "approaches" to "tiers," underscoring that BMD adoption is best understood as a flexible continuum of practices, wherein states adapt their level of implementation over time rather than locking into a single prescribed method.

The rationale provided by individual state DOTs further illustrates the cautious and staged nature of BMD adoption:

- Ohio views Approach A as the most conservative option, consisting of volumetrics supplemented with performance tests, and thus sees it as a safe entry point. Approach B offers greater flexibility by adjusting asphalt content or design air voids, with future potential to relax volumetric parameters once lab and field data are correlated.
- In contrast, the DOT agent from Indiana mentioned little utility in pursuing BMD, noting that recent specification changes to increase binder and ensure consistent bulk specific gravity G_{sb} already address durability concerns unless higher RAP or waste materials necessitate change.
- Utah emphasizes long-term performance and sustainability, prioritizing pavements that last 15 to 20 years to reduce both RAP generation and environmental burden, though the state remains cautious until stronger correlations between testing and field performance are established.

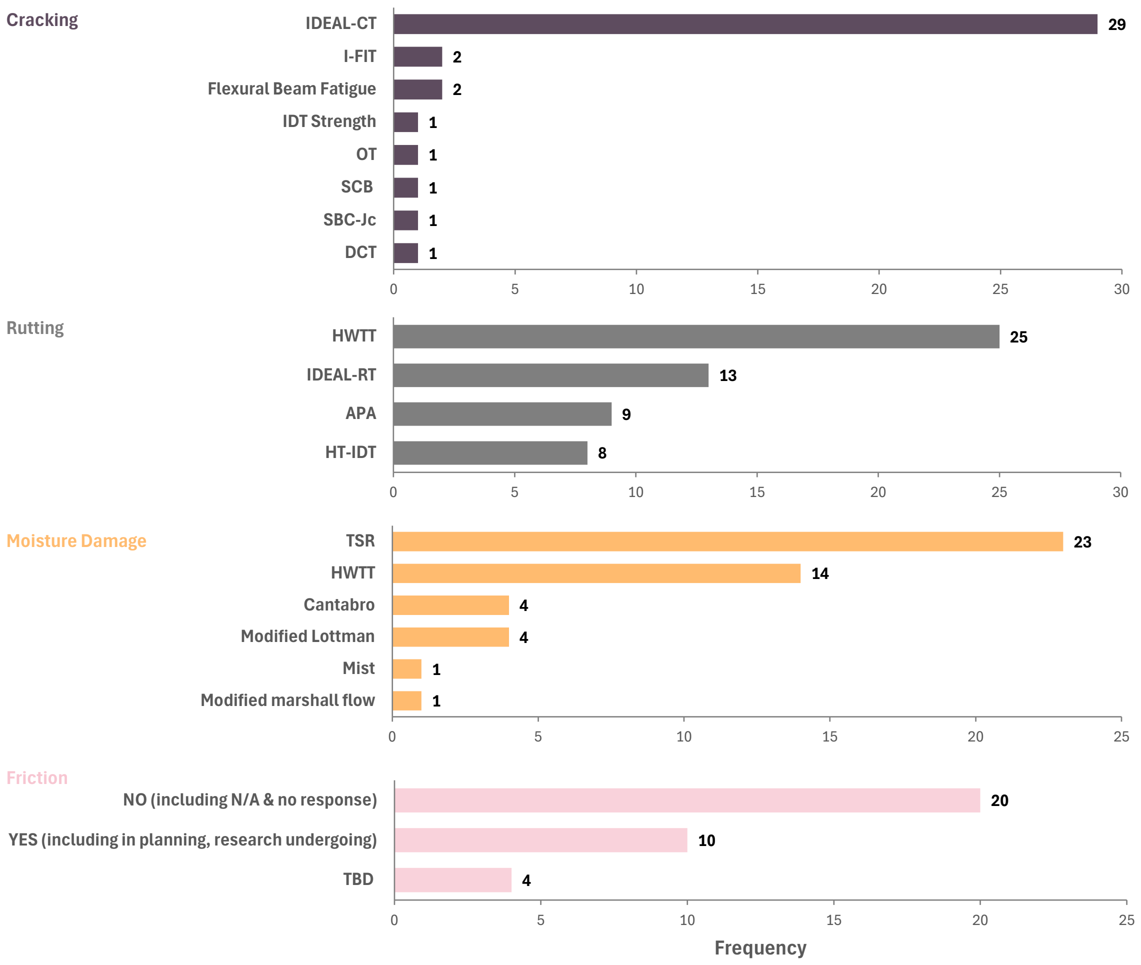
- New Jersey and Virginia emphasize that volumetric properties remain important given their demonstrated correlation with performance, while Georgia has taken the opposite stance by focusing directly on field performance and reducing reliance on volumetrics.
- Other states reflect transitional strategies: Colorado prefers a more aggressive step than Approach A, but is not ready for full BMD; West Virginia finds Approach A the most logical starting point, with possible progression to B; Arkansas is currently at Approach A, but would like to transition to Approach C or D long term. Note that this may change based on pending changes to the AASHTO PP 105 standard for BMD (i.e., changing from "approaches" to "tiers").
- Oklahoma explicitly frames adoption as a stepwise path toward Approach D.
- North Dakota envisions eventually integrating performance testing at both the design and production levels once the necessary equipment and training are in place.
- States such as Alaska and Kansas highlight context-specific concerns. Alaska applies APA rut testing to ensure mix stability when natural sands are used, while Kansas remains unconvinced that volumetric design alone is sufficient for durability and continues to evaluate rutting.
- Florida is satisfied with the service life obtained from current mixtures. The current crack-resistance performance test results are associated with a high coefficient of variation (COV). FDOT is conducting benchmarking studies focused on cracking tests and the correlation between lab crack-resistance tests and in-situ crack-resistance performance.

Collectively, these rationales show that states are not only in different stages but are also tailoring their approaches to local priorities, performance expectations, and readiness to balance volumetric and performance-based criteria.

Performance Tests

As a core component of BMD implementation, the entire procedure revolves around performance tests and corresponding performance criteria that are intended to represent the field performance of the designed mixture. The selection of appropriate performance tests directly influences pavement functionality and service life, making it a top priority in BMD-related studies. Figure 15 is a bar chart summary showing the frequency of performance tests used by state agencies in the context of BMD implementation. It is organized into four categories: Cracking, Rutting, Moisture Damage, and Friction.

Figure 15. Performance tests included or planned in your BMD process



In reviewing the overall process of BMD implementation, performance testing is required during mix design, acceptance, and QA/QC stages. These applications must also account for practical considerations such as testing capacity, duration, and the effectiveness of reflecting actual mixture performance. To explore this issue, the survey asked whether DOTs adopt the same set of laboratory tests for both performance evaluation during design and production QA/QC. The summarized responses are presented in Table 9.

Table 9. Difference of laboratory test sets for performance evaluation during mix design and production QA/QC

Use the same set?	State	Details
Yes	Nebraska	Too early to accurately answer.
	New Jersey	Mix design criteria is generally stricter because of the variability of mix during production.
	Illinois	Long-Term Aging for I-FIT is done on surface course, the LTA requirement for dense-graded mixes is 5.0 in design but is 4.0 in production which gives contractors a buffer.
	Indiana, Colorado, Virginia, Maine, North Carolina, Oregon, Florida, Alabama	These states responded that there is a consistency between design and QA/QC, with no further information provided.
No / Partially	Ohio	HWTT takes too long for QA. I'm going to assume the IDEAL-CT STOA versus reheat from plant produced will have different results. Will know more once we start getting field performance data.
	Missouri	Limit the Hamburg to 9.5 mm maximum due to production variability. With state specification provided.
	Utah	While most of our work is currently in the mix design phase, where practical, we would like to move some of that to be included with acceptance testing. Considerations include time for results, test repeatability, etc.
	South Dakota	Only at mix design. Only have thresholds for the APA and TSR tests. Still benchmarking for the IDEAL-CT.
	Vermont	HWTT is likely staying as a mix design qualification test due to test duration and amount of specimen preparation involved, and IDEAL-RT would (at the bare minimum) be done during production QA/QC testing should we find that it is an appropriate surrogate. IDEAL-CT would remain as the primary cracking test for both mix design qualification and production QA/QC testing.
	Georgia	GDOT uses AC content, gradation, in-place air voids, and profile smoothness for acceptance. For mix designs performance testing. Hamburg testing number of cycles is dependent on mix type and binder type.
	Arkansas	No performance tests used in QC/QA.
	Oklahoma	HWTT is currently only used during design, it will be potentially implemented for field testing in the future.

	Kansas	Right now we are only looking at plant produced mixes for rutting and cracking tests.
	Tennessee	Ideal CT would be used for both, but HWTT would most likely be design only with Ideal RT or HT-IDT being a part of QA/QC for expedient results.
	North Dakota	Tests have either been run at various mix design labs from consultants or at our main lab within the NDDOT. There has been no field testing conducted at testing labs on site (outside of our test trip project where NCAT brought their mobile lab). Not enough research has been conducted. Assuming issues will come from aging, specimen prep, and aggregate properties.
	Louisiana	Yes and no. HWT for design and production, SCB-J_c design; no production cracking test. Looking at modified procedures and/or IDEAL for production testing.
	Mississippi Minnesota Wyoming Alaska	These states responded with different sets of tests between design and QA/QC, with no further information provided.
Not Specified	West Virginia, Arizona, New Mexico, Hawaii, South Carolina, Connecticut, Rhode Island, Kentucky, Idaho	Unknown / not specified / still developing approach.

Across the states surveyed, there is a clear divide in whether the same set of laboratory tests is used for both performance evaluation during mix design and production QA/QC. A number of states (Nebraska, Indiana, New Jersey, Colorado, Virginia, Maine, North Carolina, Oregon, and Illinois) reported using consistent test protocols, generally applying both rutting and cracking tests at each stage to ensure alignment between mix design and production acceptance. In contrast, several states either limit certain tests to the mix design phase or employ different test sets during production. For example, Ohio and Oklahoma exclude the HWTT from QA/QC due to its time demands, while Missouri restricts its Hamburg application to 9.5 mm mixes. Utah, South Dakota, Georgia, Mississippi, Kansas, Tennessee, and others adopt partial approaches, with cracking tests (e.g., IDEAL-CT) sometimes extending into QA/QC, but more resource-intensive or less expedient tests (e.g., HWTT) confined to design. Vermont reflects a mixed or conditional approach, reserving HWTT for design while considering IDEAL-RT for production testing. A trend was noted that longer, more variable tests like the Hamburg Wheel Tracking Test (HWTT) are retained for mix design while faster, more repeatable tests such as IDEAL-CT, IDEAL-RT, or HT-IDT are adopted for QA/QC. States such as West Virginia, Arizona, New Mexico, and Hawaii have yet to specify their strategies. Collectively, this feedback underscores that some agencies maintain consistency across stages, while others modify their test sets to balance practicality, turnaround time, and resource constraints.

Table 10 summarizes state agencies' feedback on the criteria and thresholds of performance tests for both mix design and production QA/QC. Compared to the mix design stage, fewer states have established QA/QC criteria and thresholds. This gap largely reflects the different objectives of the two phases; QA/QC test methods must provide rapid, consistent, and repeatable results under production conditions. Consequently, while design thresholds are often defined at this stage due to extensive studies and data availability, the development of practical and reliable tests and acceptance thresholds for QA/QC remains a greater challenge.

Table 10. Criteria and thresholds of performance tests for mix design and production QA/QC

State	Criteria and thresholds (design)	Criteria and thresholds (acceptance and QA)
Nebraska	None determined yet.	None determined yet.
Ohio	We technically have criteria for IDEAL-CT STOA through a research project, but it's not related to field performance. The researcher used a cluster matrix, and we determined that we wanted 80% of the mixes to pass the criteria. For surface mixes, it's CT Index of 80, for a 12.5 mm intermediate it's 70 (wasn't part of research), intermediate and base (two base mixes tested) is 60. Have used them on pilot projects.	
Indiana	No criteria set.	
Missouri	https://modotgov.sharepoint.com/sites/DE/_layouts/15/Doc.aspx?sourcedoc=%7BB7B06F63-B9B3-44FD-BAFD-D26B0866B58A%7D&file=JSP2401.docx&action=default&mobileredirect=true	Same.
Utah	It depends on the product and application. For example, our standard Hamburg limitation is 10mm in 20,000 passes with a temperature dependent on the modified asphalt binder grade. Our polishing value is a minimum of 31, but only for surface courses. Our highly-modified asphalt specification has different requirements than our dense-graded asphalt mix. IDEAL-CT: no threshold established yet, we have high numbers though. Lottman Test: we use hydrated lime in all our mixtures and test occasionally for information only.	
South Dakota	APA maximum rutting is 5-8 mm at mix design, depending on the mix type. Minimum TSR is 80%, but the requirement is waived if 1.00% hydrated lime is added to the mix.	
New Jersey	HPTO (APA): Max 3.0 mm rut depth at 8,000 cycles, (Overlay): Min 1,200 cycles, TSR: Min 85 percent.	TSR not done during production.

	BRIC (APA): Max 6.0 mm rut depth at 8,000cycles, (Overlay): Min 700 cycles, TSR: Min 85 percent. BRBC (APA): Max 5.0 mm rut depth at 8,000 cycles, (FBF): Min 100,000,000 cycles, TSR: Min 85 percent. BDWSC (APA): Max 3.0 mm rut depth at 8,000 cycles, (FBF): Min 100,000 cycles, TSR: Min 90 percent High RAP: See Standard Specifications. https://www.nj.gov/transportation/eng/specs/2019/pdf/StandSpecRoadBridge%202019%2020250725.pdf	BRIC (APA): Max 7.0 mm rut depth at 8,000 cycles, (Overlay): Min 650 cycles. High RAP: See Standard Specifications.
Virginia	IDT-CT <=70, APA <8mm, Cantabro < 7.5% loss, TSR > 80%.	
Vermont	Cracking: CT-Index minimums of 45 (3/4" NMAS Type IIS mixes), 70 (1/2" NMAS Type IIIS mixes), and 85 (3/8" NMAS Type IVS mixes). Rutting: Maximum 12.5 mm (1/2") rut depth after 20,000 passes. Moisture damage: Stripping inflection point (SIP) no less than 15,000 passes.	No
Georgia	Rutting less than 12.5mm. Moisture damage requires .80 retained strength with minimum 60 psi for all specimens.	N/A
Alaska	For design: APA rutting threshold is 3 mm (at 105 F; 8,000 cycles). The APA is done according to ATM419, detailed here: https://dot.alaska.gov/stwddes/desmaterials/mat_waqtc/assets/pdf/testman/2025/2025ATMM.pdf.	NONE
West Virginia	Design: TBD.	QA: TBD
Maine	CT >150; RT>55, HWT > 20,000 passes; SIP>15,000 passes.	
Arkansas	75 CT minimum, 8mm max for PG64-22 and PG67-22 and 5mm max for PG70-22 ang PG76-22, 80% minimum retained stability.	N/A
Oklahoma	Cracking: CT-Index = 100 for surface and 60 for intermediate and base Rutting: HWTT 12.5 mm.	Just Ideal-CT has been considered and evaluated.
North Carolina	APA jr, 64C 8000 cycles.	
Kansas	TSR=80%.	
Oregon	Rutting (Hamburg): 5 mm (100 gyration mixes), 7 mm (80 gyration mixes). Moisture Damage (TSR): 80 min.	
North Dakota	None set yet. Still benchmarking and relating to field performance.	N/A
Illinois	Attached is a link to Illinois Standard Specifications for Road and Bridge Construction. https://public.powerdms.com/IDOT/documents/1945348/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202022 See page 874 Section 1030.05(c) for Tensile Strength and **TSR** requirements See page 875 Section 1030.05(d)3 for the **Hamburg** Wheel Test requirements See page 875 & 876 Section 1030.05(d)4 for the **I-FIT** requirements. Attached is the link to the Manual of Test Procedures for Materials: https://public.powerdms.com/IDOT/documents/2966431	Links to the specs attached above.

Alabama	Cracking: 50, 75, 100 depending on the ESAL range Rutting: 20 PSI TSR: 0.80 minimum.	
Louisiana	Cracking: Low ADT - 0.5, High ADT - 0.6 kj/m2 Rutting: Low ADT - <10mm, High ADT - <6mm @ 20k; no SIP. TSR: >80%.	Same or N/A
No details provided: Colorado, Wyoming, Arizona, Arkansas, Mississippi, New Mexico, Tennessee, Minnesota, Hawaii, South Carolina, Connecticut, Rhode Island, Kentucky, Idaho, Florida.		

Aging for BMD Implementation

To simulate field distress resistance, adequate and appropriate aging conditioning on both mix design samples and QA/QC samples is critical, especially for cracking resistance. Table 11 shows the current adoption of aging protocols for performance tests. Across states, there is broad reliance on Short-Term Oven Aging (STOA) at 135°C for two to four hours as the baseline for mix design and, in some cases, QA/QC. Long-Term Aging (LTOA) is less consistently applied, typically six to 24 hours at 95 to 135°C, depending on the test purpose (cracking vs. durability). Common Practice is STOA for two hours at 135°C (Nebraska, New Jersey, Oregon, Virginia, Illinois, Arkansas). Some other states adopt extended conditioning, in which some states apply four hour STOA (Indiana, Oklahoma) or LTOA of 20 to 24 hours (Virginia, Oregon, Vermont under evaluation). Besides these states, Ohio, Vermont, Tennessee, and Oklahoma rely on reheated plant-mixed samples for QA/QC instead of conditioning with STOA. Several states either have no defined procedures yet (Wyoming, Colorado, Alaska, Arizona, Arkansas, Minnesota, New Mexico, Hawaii) or are evaluating protocols (West Virginia TBD, Maine undetermined, Georgia does not require for acceptance). The feedback reflects the ongoing national inconsistency in selecting appropriate aging protocols for both design and acceptance in BMD.

Regarding whether the same aging protocol is used for mix design and QA/QC, roughly half of the states with defined procedures use the same protocols for both design and QA/QC, while the rest either shorten or modify them in QA/QC or are still undecided.

- Yes (Consistent): Nebraska, Indiana, Missouri, Utah, New Jersey, Virginia, Maine, North Carolina, Mississippi, Oregon, Illinois (mostly consistent, except STOA skipped in production acceptance), Alabama, and Louisiana (QC looking at utilizing unaged with shift factor for SCB-J_c). These states aim for alignment between design and production testing, ensuring comparable performance results.
- No / Partially (Different): Ohio, Vermont, Oklahoma, Tennessee, North Dakota, and Arkansas. These states typically apply STOA during mix design but relax or do not use it during QA/QC, often relying on reheating or plant-mix handling to speed up turnaround.

- Undecided / Not Specified: Wyoming, Colorado, Alaska, Arizona, Minnesota, West Virginia, New Mexico, Hawaii, Georgia, and Florida. These states either have no defined QA/QC protocols or have not yet harmonized them with design procedures.

Table 11. Aging protocols for performance tests

State	Aging protocols		Same aging for design and QA/QC?
Nebraska	R	STA 2 hrs @ 135.	Yes
	C	LTA 6 hrs @ 135. may shorten up to 4 hrs @ 135.	
	M	t283".	
Ohio	R	AASHTO R 30 (2 hrs). Hot-compacted and reheat for QA follows Supplement 1033.	No Hot-compacted and reheat for QA follows Supplement 1033."
	C	AASHTO R 30 (2 hrs) for STOA and R 121 Method D for LTOA. Hot-compacted and reheat for QA follows Supplement 1033.	
	M	M: With our current TSR protocol (Supplement 1051) it is 4 hrs at compaction temperature.	
Indiana	R	4 hr conditioning for mix design. 2 hr for field samples. 300F.	Yes
	C		
	M		
Utah	R	https://drive.google.com/file/d/161yEeUdD99VsEw-qKpnGr0WrubBQ6laH/view?usp=sharing	Yes
	C	https://drive.google.com/file/d/16mRHBAtSqUS3E_oZXzw_IKc2PXPY6hsT/view?usp=sharing	
	M	Currently, we use the Hamburg test, except in research.	
South Dakota	R	APA tested at high temp of the PG Binder specified.	
	C	20 hr aging at 110 degrees Celsius for IDEAL-CT.	
	M	SD309 (SDDOT Materials Manual).	
New Jersey	R	Short term aging only is used for all performance mixes "condition the mix for 2 hrs according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, ensure that the mix is short term conditioned for 4 hrs according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312)."	Yes
	C	Same comments as rutting tests.	
	M	Same comments as rutting tests.	
Virginia	R	2 hr short term aging.	Yes
	C	4 hr short term aging, 6 hr long term aging at compaction temperature.	
	M	None.	
Vermont	R	Reheated PMLC specimens: N/A LMLC STOA (mix designs & aging done by Producers): 2 hrs at 135 degrees C All HWTT testing done at 45 degrees C.	No. Mix design is typically STOA; all testing done by our agency after mix design approval has involved reheated PMLC mixes.
	C	Reheated PMLC specimens: N/A LMLC STOA (mix designs & aging done by Producers): 2 hrs at 135 degrees C per AASHTO R 30. LTOA: Not yet required in procedures or specifications, but VTrans is currently evaluating 20 hrs at 110 degrees C per AASHTO R 121, Method D.	
	M	Reheated PMLC specimens: N/A LMLC STOA (mix designs & aging done by Producers): 2 hours at 135 degrees C All HWTT testing done at 45 degrees C	
Georgia	R	AASHTO T 324.	Other: Don't require it for acceptance.
	C	ASTM D8225.	
	M	AASHTO T 283.	

Arkansas	R	N/A.	Other : No performance testing for QA/QC.
	C	2 hrs short term aging R30.	
	M	N/A	
Oklahoma	R	4 hrs at 135 C.	No. We evaluated reheating the specimen and also hot compaction, we recommend the re-heating to compaction temperature for a maximum of 2 hrs.
	C	4 hrs at 135 C.	
	M	2 hrs at 135 C.	
Mississippi	R	2 hr aging at compaction temp.	
	C		
	M		
Kansas	R		Not looking much at design.
	C	Sample, allow to cool, reheat to 275 F for 1.5 to 2 hrs with mix at a 1/2"" depth in pan.	
	M	KDOT method KT-56.	
New Mexico	R		
	C		
	M	T283.	
Tennessee	R	2 hrs at 135 C as loose mix.	No. No STOA when using plant mix.
	C	4 hrs at 135 C as loose mix.	
	M	2 hrs at 135 C as loose mix.	
Oregon	R	PMLC: heat to placement temperature for 1 to 1.5 hrs. LMLC: Short-term aging at 135° C for 2 hrs.	Yes.
	C	PMLC: Long-term aging at 95° C for 24 hrs. LMLC: Short-term aging at 135° C for 2 hrs; LTA at 95° C for 24 hrs.	
	M	No aging; heat to compaction temperature and compact. LMLC: 2 hrs at compaction temperature.	
North Dakota	R	Following standards.	No acceptance or verification testing to compare.
	C	Variable for research purposes.	
	M	Following standards.	
Illinois	R	Hamburg Wheel, IL mod AASHTO T 324 (MoTP pages 265- 270).	We use the same aging protocol except acceptance of production mix does not require short term aging. See IL mod AASHTO R 30.
	C	I-FIT Unaged (short-term aged), I-FIT long-term aged on prepared specimens. See IL modified AASHTO T 393 (MoTP pages 279-281) and IL mod AASHTO R 30 (MoTP pages 293-295).	
	M	Tensile Strength & TSR, IL mod AASHTO T 283 (MoTP pages 181-189).	
Alabama	R	2 hr	Yes.
	C	2 hr	
	M	2 hr	
Louisiana	R	2 hr	Other: Verification yes. QC looking at utilizing unaged with shift factor for J_c.
	C	5 day 85 C	
	M	Modified Lottman protocol.	

	R C M	TBD / not provided / undetermined at this time / under review: Missouri, Wyoming, Colorado, Alaska, Arizona, West Virginia, Maine, North Carolina, New Mexico, Minnesota, Hawaii, South Carolina, Connecticut, Rhode Island, Kentucky, Idaho, Florida.

Lag/Dwell Time

Table 12 lists state agencies' feedback on lag/dwell time requirements. Only a few states (Nebraska, Missouri, Kansas, Oregon) have explicit and detailed lag/dwell time protocols, with limits ranging from 24 hours to two weeks or strict reheating/conditioning procedures. A larger group of states reported no requirements, and approximately one dozen others fall into the other/conditional category, where practices are guided by research, internal procedures, or ongoing evaluations rather than formal specifications.

Table 12. Presence of lag/dwell time requirements

Lag/dwell time requirements	State
Yes (explicit requirement exists)	– Nebraska: Max lag time = 7 days, dwell time = within 24 hrs. For QA/QC, reheating may be mandated. – Missouri: Plant-compacted only; minimum lag time; maximum dwell time = two weeks. – Kansas: Within 96 hrs of collection, reheat & age at 275°F (135°C) for 90 to 120 min.; compact within 120 min.; cool 1 to 2 hrs; condition in water bath (77°F, 60±5 min); test within 5 min. of removal. – Oregon: Not currently, but requirement will likely be specified in future.
No (no requirement specified)	– Indiana, South Dakota, New Jersey, Wyoming, Virginia, Vermont, Oklahoma, North Carolina, Mississippi, North Dakota, Alabama, Louisiana, Arkansas. – Ohio: For IDEAL-CT STOA mix design, required dwell time ≥ 16 hrs.
Other / Conditional / Under Evaluation	– Utah: samples made day 1, tested day 2. – Georgia: follow established procedures, no explicit requirement. – Tennessee: no requirement currently; following ongoing research. – Illinois: Recommend I-FIT specimens be tested within three weeks of production. – Minnesota: not specified. – New Mexico: not specified. – Arizona: not specified. – West Virginia: TBD. – Maine: still being determined. – Hawaii: under review. – Colorado: N/A. – Alaska: N/A. – Florida: not specified.

Several states provided their comments on the impacts of lag/dwell time on test results:

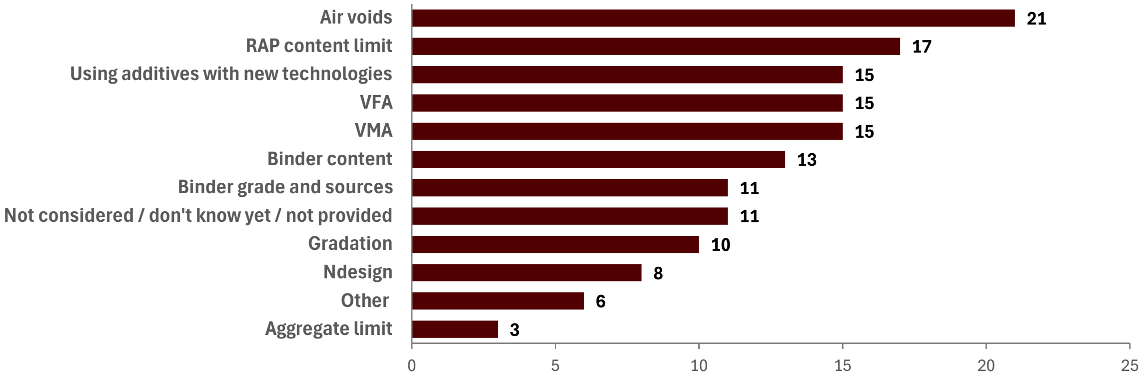
- Nebraska: We think the limits stated above will reduce this variability to be negligible.
- Ohio: Didn't do one, but based it off TSR research done in the early 2000s.
- Indiana: I'm sure it played into our interlaboratory variability.

- Utah: YES! The test results change if you don't follow a consistent procedure. The Hamburg test results improve over time, but the cracking numbers don't and seem to get lower.
- Missouri, Oregon, Illinois: Yes.
- New Jersey: We don't have a lot of information regarding lag time. We've not seen any noticeable impact from dwell time.
- Virginia: We did see a difference.
- Oklahoma: It's not clear; some mixes exhibited changes, some didn't. More research will be done on this topic.
- Kansas: Yes, the time between sampling and molding is allowed to be up to 96 hours, but we are seeing that this time range may be introducing some variability in CT results.
- North Dakota: Based on research, yes, this is something that will need to be established.

Section 3. Relationship with Volumetric Design

It has been widely discussed how volumetric requirements may be adjusted, relaxed, or eliminated as agencies implement BMD, since BMD shifts the emphasis toward mechanical/performance tests (e.g., cracking, rutting, moisture damage), rather than volumetrics alone, and attempts to relax the volumetric criteria to meet the performance measure. Figure 16 shows state DOT feedback on potential adjustments or relaxations to volumetric requirements that may be considered during the implementation of BMD approaches.

Figure 16. Potential adjustments or relaxations to volumetric requirements in your state's specifications that may be considered during the implementation of BMD approaches



Fourteen states shared their experiences on the potential adjustments or relaxations to volumetric requirements listed on Table 13. Lowered or adjusted air voids targets, relaxation or elimination of VFA requirements, gradation flexibility, N_{design} reductions, binder content, binder source, and RAP allowance increases are reported in their BMD implementation, all of which are driving greater flexibility in volumetric specifications.

Table 13. Examples of any potential adjustments or relaxations to volumetric requirements in your state's specifications

State	Examples of any potential adjustments or relaxations to volumetric requirements
Virginia	Opened up the gradation; eliminated the VFA requirements.
Georgia	GDOT has never required volumetric testing for QC acceptance.
Nebraska	We have already lowered air voids at N_{des} in 2008 to promote higher binder contents.
Missouri	Allow lower air voids and VFA waived if meet Hamburg.
Utah	1% air voids at 50 gyrations with the VFA between 90 to 95%. The VMA was also increased 1%.
New Jersey	We've removed minimum AC content requirement from HPTO specification and lowered N_{design} requirements, increased the allowable RAP percentage using performance specification.
Vermont	Air voids, gradation, and some aggregate consensus property requirements (such as fine aggregate angularity) may be relaxed. Binder source changes during mix production will likely be restricted as a result of implementing BMD.
Arkansas	Minimum design air voids, no VMA requirement, no gradation control points, minimum gyration level for BMD. Have already implemented lower air voids and N_{design} for all standard mixes. All mixes at 3.5% air voids. Surface mixes at 60 gyrations, Binder and base mixes at 75 gyrations.
Maine	Eliminated gradation control points below 4.75mm sieve; target air voids; VMA minimum.
Kansas	We may consider adjusting target air voids from 3.0% to a value within a certain range.
Oregon	May relax design air voids to 3.0-3.5% and potentially VMA upper limits.
Illinois	Illinois no longer requires VFA. RAP Content Limit determined by design and I-FIT (Flexibility Index requirements).
Alabama	No RAP limit, but if over 35% DFT testing required, allow different grades of AC if criteria met.
Louisiana	Air void range; binder substitutions, binder additives.

The implementation of BMD has prompted many states to reconsider traditional gyratory compaction levels (N_{design}), with a clear movement toward lowering compaction efforts to enable higher binder contents and more durable mixtures; see Table 14. A trend toward lowering compaction effort is evident in states like Nebraska, Utah, Missouri, Vermont, and Ohio, where reducing or eliminating high N_{design} levels is seen as key to achieving balanced performance (e.g., greater binder content, improved cracking resistance). However, many states remain cautious or undecided, with some explicitly retaining current compaction levels until more field performance data is available. This reflects a split adoption landscape; some agencies are proactively moving toward 50 to 60 gyration standards or full N_{design} elimination, while others hold back, favoring traditional Superpave compaction until BMD outcomes are better established.

Table 14. Feedback on compaction efforts

State	Feedback
Adopted reductions / considering adjustments	
Nebraska	Reduced compaction as early as 2008, with most mixes now designed at 50 to 60 gyrations.
Missouri	Lowered N_{design}.
Utah	Explicitly changed N_{design} to 50 gyrations.
Vermont	Actively discussing eliminating high N_{design} values (80 gyrations) altogether, citing BMD research and compaction issues.
Ohio	N_{design} will eventually be phased out entirely under full BMD implementation.
North Dakota	Anticipates lowering compaction; currently most mixes are still at 75 gyrations.
West Virginia	Reported TBD.
Illinois	Marked as TBD, suggesting ongoing review.
Louisiana	Reduced as part of BMD spec.
Arkansas	Minimum of 50 gyrations for BMD.
No changes / not currently	
Virginia, Georgia, Oregon, Kansas, North Carolina, Oklahoma, Maine, Alabama.	
No information provided	
Mississippi, Tennessee, Minnesota, New Mexico, Alaska, Arizona, Hawaii, Florida.	

Section 4: Gaps and Challenges

This section summarizes the primary challenges that state DOT agencies encounter in implementing BMD, shown in Figure 17, and the most commonly heard feedback or concerns from contractors listed in Table 15.

Figure 17. Primary challenges that your DOT agency encounters in implementing BMD

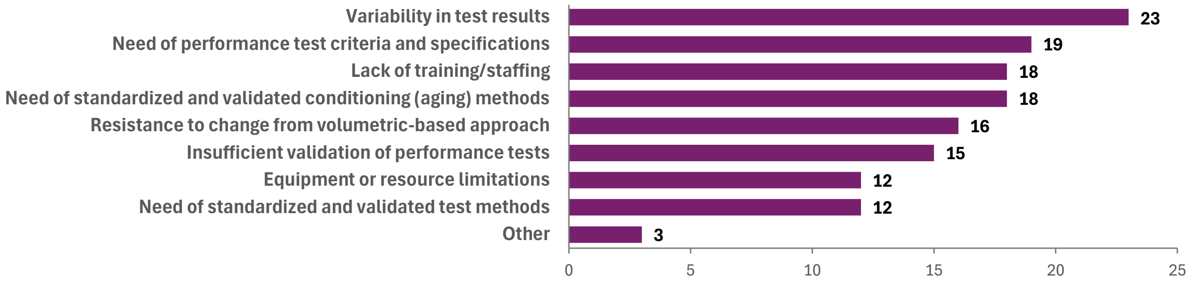


Table 15. Most commonly heard feedback or concerns from contractors

State	Most commonly heard feedback or concerns from contractors
Nebraska	We have mutual concern over variability and repeatability, and how fast you will have acceptance test results completed when the plants are producing 4000 tons per day. If pay factors and test results take more than a day for acceptance and pay factors, that will be an issue.
Ohio	Biggest items are the initial costs, especially once we get to the QA side. I think project costs will be more while in Approach A and B due to the desire of needing to run volumetrics and most likely needing multiple technicians at a mix plant that typically did fine with one. If it's agency acceptance, then that may help with this. Contractors can determine what an offset is for hot-compacted pills versus reheat and perform that as needed. May still require an AC content.
Utah	They have been positive about our move to HiMod high density mixtures. They find the mix more sustainable than SMA and prefer it. Our HiMod uses regular dense-graded aggregates and does not require the expensive gap-graded aggregates used with SMA.
New Jersey	Not being able to use performance testing for quality control, variability of test results, time consuming tests.
Virginia	Initial cost of equipment was high; time requirements restricting.
Vermont	Smaller contractors are concerned about investing in needed equipment and the costs associated with shipping materials to third-party labs to have BMD testing conducted, but have otherwise been somewhat supportive. Larger producers have concerns about us moving too slowly/not being innovative enough in our specifications as currently written. They would also like to see more investment done on validating criteria for BMD.
Georgia	Costs and validation of specified tolerances.
Arkansas	Testing time. Mixes pave and compact better.
Maine	Equipment; test time; staffing.
Oklahoma	Concern about the changes to pay factors, design methods, and equipment.
Mississippi	Equipment investment.
Kansas	We don't have a problem. Why change?
Tennessee	Equipment investment.
North Dakota	There isn't a knob at the plant to turn to increase cracking resistance.
Illinois	Increased testing costs and testing time and limited staffing.
Alabama	Increased testing times and how do pay factors work with BMD.
Louisiana	Time and equipment.

Summary and Analysis of Second Round Survey

General Overview of Second Round Survey

The second round survey was designed to build on the results of the first round survey conducted earlier in 2025 and gather more in-depth information from state transportation agencies on their ongoing and planned practices within the Balanced Mix Design (BMD) framework. Responses help identify common challenges, gaps, and regional trends to support the development of a consistent and efficient QA/QC framework for BMD implementation across SASHTO member states. The detailed second round survey questionnaire is listed in Appendix A4. The following state transportation agencies provided valuable feedback in the survey: Alabama, Arkansas, Georgia, Kentucky, Louisiana, Mississippi, Oklahoma, and Virginia.

Section 1. Current (Planned) QA/QC Testing Practices

This section asked respondents to describe what QA/QC testing and verification practices are used for asphalt mixtures in flexible pavements, covering both traditional constituent and volumetric verification and performance-based testing. Specifically, it requested the tests currently used for constituent and volumetric verification, the performance tests and aging protocols currently employed (e.g., IDEAL-CT, HWTT, SCB, TSR, STA/LTA), and any anticipated performance tests and aging protocols for future adoption. It also asked whether the same performance tests are currently used or planned for both mix design and QA/QC/acceptance. Respondents were asked to indicate yes/no/partially and explain the rationale, with common considerations including turnaround time, production variability, the lack of established thresholds, equipment availability, and whether surrogate tests are still being evaluated. The feedback from state DOT agents regarding current constituent and volumetric verifications, as well as performance tests currently used or planned for use, is summarized in Table 16.

Table 16. Current (planned) QA/QC testing practices
(constituent/volumetric verification and performance tests)

State	Con. & Vol. QA/QC (current)	Perf. tests in prod. (current)	Perf. tests in design (current)	Aging protocol (current)	Planned / in discussion
AL	All aggregate for QPL; Density, AV, AC; Grad (OGFC).	np	HWTT, TSR (design only).	np	IDEAL-CT, HT-IDT in production (keep HWTT/TSR in design).
AR	AV; Binder/AC; Gmm; In-place density.	np	APA; IDEAL-CT; Retained Stability.	2 hr STOA	No change; exploring friction tests.
GA	Acceptance mainly: AC + Grad + in-place AV (volumetrics only in design).	— (no perf. testing required for acceptance).	HWTT; Permeability; IDEAL-CT; Abrasion loss (for field mix design verif).	np	TBD / under discussion.
KY	Superpave (AASHTO M323) ; Asphalt Content (T308 or T164).	IDEAL-RT or HT-IDT with IDEAL-CT (information).	IDEAL-CT & HWTT (Design).	np	np
LA	QC: AC (ignition), Grad, VTM/VFA/VMA; QA: Mat density, Smoothness.	LWT at start of JMF + every 20k tons.	np	STOA (used)	Increase LWT frequency; add SCB; STOA w/ shift factor; ANN model for SBC J_c test.
MS	Gradation; AC; Gmb; Gmm.	np	np	2 hrs at compaction temp.	HWTT, IDEAL-CT, Cantabro, IDEAL-RT (maybe HT-IDT).
OK	Binder/AC; Grad; Lab density; In-place density.	TSR	np	np	IDEAL-CT (reheated to compaction temp specimens).
VA	Acceptance: AC, Gradation; Verification: Superpave volumetrics for .	IDT-CT; IDT-HT; Cantabro; TSR (first 4000 tons); APA Jr (as requested).	IDT-CT, APA, Cantabro and IDT-HT.	No production aging protocol; conditioning: CT 1 hr, HT 2 hr.	LTOA research completed; no decision yet.
Note: Con. & Vol.: constituent & volumetric; Perf. Tests: performance tests; np: not provided.					

The section also asked for feedback on balancing the adoption of long-term aging (LTA), often utilized as important conditioning for cracking-related performance tests, against the longer testing time it requires, especially since short-term aging (STA) is commonly used in design due to practicality and turnaround-time constraints. States generally recognize that aging is important, especially for cracking evaluation, but they diverge on where and to what extent aging is feasible without undermining turnaround time for production decisions, as shown in Table 17. A common consideration is separating design-phase aging from production-phase constraints; agencies are more willing to require LTA (or LTA-like conditioning) for mix design qualification than for routine production acceptance, where delays can disrupt paving procedures.

Table 17. State DOT feedback on how to balance the importance of LTA and the extended testing time it entails

State	Thoughts on how to balance the importance of LTA and the extended testing time it entails
AL	N/A
AR	—
GA	This is something I think needs more research to help decide on a consensus between the two.
KY	KY has been looking at the LTA informationally in the design phase with goals to include LTA requirements on highest classification roads.
LA	LADOTD developed a shift factor to apply for mixtures in Louisiana. Aging is critical for cracking test and the test's ability to capture performance.
MS	I feel like there could be a happy medium found in regard to aging time and prolonging the total testing time.
OK	Requiring long-term testing during production would significantly delay results and ODOT is not considering that option, currently we are exploring different STA and reheating procedures during production.
VA	Virginia only requires LTA for mix design, not for production sampling. Virginia's research council has a report that has come up with a LTA protocol that requires a max of 6 hrs aging before compaction. We haven't decided to adopt the protocol yet for the production.

Section 2. Performance Criteria and Thresholds

Table 18 summarizes state DOT feedback on whether and how performance criteria and threshold values are being established for asphalt mixture testing. Overall, agencies most commonly rely on a combination of benchmarking datasets (statewide or project-based), targeted research studies (often with universities or institutes such as the National Center for Asphalt Technology [NCAT]), and, if available, correlation with historical and observed field performance. Several states also noted using statistical methods and incorporating industry input to interpret test variability and support defensible preliminary design thresholds. At the same time, a few agencies indicated that thresholds are still not defined, reflecting the early and evolving nature of performance-criterion development in some states.

In contrast, thresholds for plant-produced mixtures in QA/QC are generally less mature and remain "not yet determined" in more states. Multiple DOTs emphasized that they are still collecting production data, conducting information-only testing, or planning to evaluate QA/QC criteria through pilot specifications before setting acceptance thresholds. Some states also expressed uncertainty regarding whether aging/conditioning protocols for plant-produced mixtures should match those used in mix design, particularly given the potential effects of reheating and conditioning time. Virginia provided an example of applying different cracking-test thresholds for reheated versus non-reheated plant-produced samples, underscoring a broader trend that production thresholds may ultimately need to be adjusted to reflect sampling and conditioning realities in the field.

Table 18. State DOT feedback on whether and how performance criteria and threshold values are being established for asphalt mixture testing

State	How were performance criteria and thresholds established?	
	Design	**Plant-produced**
AL	N/A	N/A
AR	Thresholds were determined through a research project done by the University of Arkansas in Fayetteville.	No current plans to implement performance tests for QA/QC.
GA	Georgia had NCAT do a research project for benchmarking our mixes. Georgia is also collecting data for IDEAL CT and abrasion loss to help in determining those thresholds.	Not yet determined.
KY	Statewide data collection (benchmarking), in-house research, historic performance correlation, industry feedback.	Not yet determined. Production values are different (higher) than design and work is ongoing to understand why/how/when.
LA	Research projects; pilot studies; and most importantly field performance correlation.	Not yet determined. Will evaluate during pilot specification.
MS	No thresholds yet.	Not yet determined. Unsure of aging conditioning yet but I predict we will have threshold values adjusted for plant-produced mix.
OK	Based on design and production benchmarking studies, using cumulative distribution analysis and other tools.	No. Currently testing for information only and gather data for analysis.
VA	Virginia did research on benchmarking existing Superpave designs. Based on that research Virginia set design thresholds to meet or improve the performance testing.	For plant-produced samples, there are different thresholds for reheat and non-reheat cracking test samples.

Section 3. Pay Factors, Schedule, and Specification Integration

The survey asked about the role of BMD performance tests in the integration of pay factors, schedule, and specifications. Table 19 demonstrates that BMD performance test results are generally not yet integrated into respondent states' pay-factor or acceptance frameworks, reflecting ongoing concerns about how to apply pay adjustments, confidence, and variability in results, especially for cracking tests. Alabama and Arkansas noted that clearer methods and stronger confidence in cracking test outcomes are needed before pay factors are feasible. Louisiana and Kentucky indicated pay-factor integration is not in place yet, with Kentucky anticipating pilots as the next step, while Louisiana cited variability as a barrier in the near term. Oklahoma similarly is holding off until IDEAL-CT variability improves (targeting ~20% COV), and Virginia reported only preliminary discussions (e.g., combined pay factors) with no formal adoption. Georgia also indicated that BMD is not yet implemented.

Regarding construction scheduling impacts, only Georgia and Oklahoma expect extended performance-testing turnaround times to affect schedules, while Kentucky and Louisiana do not. Arkansas, Mississippi, and Virginia remain uncertain, suggesting that schedule impacts are still being evaluated and likely depend on how performance testing is ultimately incorporated into QA/QC workflows.

Table 19. Status of integrating BMD performance tests into acceptance/pay factors and construction scheduling

<table>
<tr><th>State</th><th colspan="2">Has your agency integrated BMD-related performance test results into pay-factor or acceptance frameworks? If not, any ideas or comments?</th></tr>
<tr><td>AL</td><td colspan="2">No, we would be further along if we knew how to apply pay factors to performance tests.</td></tr>
<tr><td>AR</td><td colspan="2">We would need much more confidence in performance (cracking) test results.</td></tr>
<tr><td>GA</td><td colspan="2">GDOT still hasn’t implemented BMD.</td></tr>
<tr><td>KY</td><td colspan="2">Not yet but plan to with pilot projects.</td></tr>
<tr><td>LA</td><td colspan="2">No. Not tied to pay at this time. Variation may prevent in the near term.</td></tr>
<tr><td>MS</td><td colspan="2">No .</td></tr>
<tr><td>OK</td><td colspan="2">Not yet until observed IDEAL-CT variability decreases under an average of 20%.</td></tr>
<tr><td>VA</td><td colspan="2">Virginia has not worked it into the acceptance framework. There are talks of combined pay factors to incorporate performance testing but nothing official.</td></tr>
<tr><th colspan="3">Do you expect extended testing time for performance-based QA/QC to influence construction schedules?</th></tr>
<tr><td>Yes</td><td>■■</td><td>GA, OK</td></tr>
<tr><td>No</td><td>■■</td><td>KY, LA</td></tr>
<tr><td>Uncertain</td><td>■■■</td><td>AR, MS, VA</td></tr>
<tr><td>N/A</td><td>■</td><td>AL</td></tr>
</table>

Section 4. Tiers of BMD (New AASHTO Standard)

In April 2025, the Balanced Mix Design (BMD) Implementation Working Group (IWG) presented a new standard of BMD practice [15]. The proposed standard shifts the focus toward how agencies specify and implement BMD mixtures, thereby allowing greater flexibility in mix design. The framework also moves from four “approaches” to three “tiers,” which reflect the level of specification and the degree of flexibility permitted in constituent selection and volumetric requirements. As an agency progresses through the tiers, greater reliance is placed on mechanical performance testing and less on constituent and volumetric specifications. The tiered approach is generally viewed as a practical way to phase in performance testing and align requirements with agency readiness, contractor capability, and risk tolerance. Table 20 summarizes the state DOT feedback on the current status and comments on the BMD tier classification.

Table 20. State DOT feedback on current status and comments on BMD tier classification

State	Current status regarding tier classification? What are your general thoughts on this tiered approach, and how might it be integrated into your QA program and contractor QC practices?
AL	– Tier 1. – If we had pay factors for performance tests, we would move to Tier 3.
AR	– Tier 1.
GA	– Although GDOT hasn't implemented BMD, Tier 3 would probably fit our approach.
KY	– Kentucky needs buy-in from industry through BMD testing, but a tiered approach makes sense.
LA	– Tier 2. – Agree with it. Provides a pathway to achieving performance-designed mixtures.
MS	– N/A. – I am a fan of the tiered approach.
OK	– Our current practice would align with Tier 2.
VA	– Virginia would fall into Tier 2.

Section 5. Roadmap of BMD Implementation

Table 21 illustrates the roadmap with a spectrum of maturity across eight southeastern U.S. states. Many states have completed or progressed through early steps, planning, identifying needs, selecting candidate tests, and BMD database and benchmarking, while later steps, such as formal specs, accreditation, and full implementation, remain in progress or planned.

Table 21. Roadmap of BMD implementation by state DOT feedback

Tasks		State							
		AL	AR	GA	KY	LA	MS	OK	VA
Task 1: Overall Planning	– Initial consideration		C		C	C	✓	✓	C
	– Identifying issues and resources				C	C	✓	✓	C
	– Formation of a stakeholder panel	C			C	C		✓	C
Task 2: Distress & Performance Tests	– Leverage existing state-developed mechanical tests				C	C	✓	✓	C
	– Evaluate new performance tests for mix design		C		C	IP	✓	✓	C
	– Evaluate new performance tests for QA				IP	IP	✓		C
	– Validate tests (feasibility, repeatability, production, inter-lab variability)	C	IP		IP	IP			C
Task 3: Resources & Equipment	– Acquire equipment; manage resources; conduct initial training		C		C	IP	✓	✓	C
	– Conduct inter-laboratory studies	C			C	C		✓	C
Task 4: BMD Database & Benchmarking	– Review historical/performance management data	C			C	C		✓	C
	– Benchmark using state mix categories	C	C		C	C	✓	✓	C
	– Run shadow projects; analyze production data	C			C	C		✓	C

	– Adjust requirements as needed (aggregate/volumetrics/RAP/RAS/additives)	C	C		IP	IP		✓	C/IP
Task 5: Specs & Program Development	– Develop QA sampling/testing protocols incorporating performance tests				C	IP		✓	C
	– Evaluate surrogate acceptance tests correlated to design tests	IP			IP	IP			
	– Develop specs/policies for pilots		C		C/IP	IP		✓	C
	– Conduct pilot projects		IP		IP	C/IP		✓	C
	– Update/modify specs as needed		IP		IP	PL		✓	C
Task 6: Training & Accreditation	– Develop/update BMD training and certification	C			IP	C/IP		✓	C
	– Implement statewide proficiency testing	C			IP	PL			
Task 7: Initial Implementation	– Technology transfer to industry/agency (requirements, procedures)				C/IP	C/IP/PL		✓	C
	– Define scope and select projects	IP			C/IP	C/IP/PL		✓	C
Task 8: Full Implementation	– Implement BMD for all or selected state mix categories				IP	C		✓	C/IP/PL
Note: C: completed; IP: in progress; PL: planned; ✓: checked without indicating specific implementation status.									

Three states (Louisiana, Oklahoma, and Virginia) provided a detailed timeline of the BMD implementation roadmap. The timeline listed in Table 22 highlights three instructive implementation trajectories.

- Louisiana began planning and test selection early, between 2009 and 2012; implemented SCB for cracking; and built supporting databases and equipment capacity between 2014 and 2016. Current efforts focus on extending performance testing into QC applications through pilots and refining specifications based on ongoing evaluation for 2026.
- Oklahoma's program is more recent and structured, with most major planning, testing, equipment, benchmarking, and specification development activities completed between 2018 and 2024, followed by initial implementation in 2024 and 2025 and broader practice targeted for 2026.
- Virginia demonstrates a multi-stage development that started with initial consideration and benchmarking in 2016 to 2018; shadow testing and pilots in 2018 and 2019; refinement of performance tests and procedures, including adoption of an IDT-CT variant in 2021 and associated precision study; and continued adjustments to requirements as field experience accumulated. Virginia advanced to initial implementation in 2023 and reported full implementation by 2025, with continued specification refinements based on performance observations.

Table 22. Timelines of BMD implementation by Louisiana, Oklahoma, and Virginia

Tasks		State		
		LA	OK	VA
Task 1: Overall Planning	– Initial consideration	2009 to 2012.	Done in 2018.	Initial consideration started in 2016. Identifying issues and resources in the fall of 2017. The formation of a stakeholder panel specific for BMD was created in the winter of 2018.
	– Identifying issues and resources			
	– Formation of a stakeholder panel			
Task 2: Distress & Performance Tests	– Leverage existing state-developed mechanical tests	SCB was selected in 2012, implemented in 2016.	Done in 2018 to 2019.	In 2018, the paving season in Virginia identified APA, Cantabro, and IDEAL-CT tests for performance. In 2021, Virginia implemented using IDT-CT, very similar to the IDEAL-CT, with some variation in testing parameters and specimen conditioning. In 2021, Virginia research also showed precision through COV in single lab.
	– Evaluate new performance tests for mix design			
	– Evaluate new performance tests for QA			
	– Validate tests (feasibility, repeatability, production, inter-lab variability)			
Task 3: Resources & Equipment	– Acquire equipment; manage resources; conduct initial training	DOTD District labs have HLWT; Contractors' design labs have HLWT and Load Frames; 2014 to 2016.	Done in 2018 to 2024.	In 2021 equipment recommendations and acquisitions were made for the agency labs. In 2020 IDT-CT cracking performance test had round robin testing occur and the report came out in 2022.
	– Conduct inter-laboratory studies			
Task 4: BMD Database & Benchmarking	– Review historical/performance management data	2012 to 2016.	Done in 2018 to 2024.	Historical data and Benchmarking started in 2016 when the initial BMD idea was introduced. Shadow testing was conducted in 2018 but pilot projects were conducted in 2019. (1) gradation bands were widen for BMD design. (2) 2026 the VFA production requirement has been lifted and is report only. (3) In Virginia there have been pilot projects and continued research on increasing rap, using GRT and processed plastics. (4) Virginia has also done research and pilot projects on recycling agents additives and are still determining how to accept those products.
	– Benchmark using state mix categories			
	– Run shadow projects; analyze production data			
	– Adjust requirements as needed (aggregate / volumetrics / RAP / RAS / additives)	Adjustments being evaluated currently for new specification.		

Task 5: Specs & Program Development	– Develop QA sampling/testing protocols incorporating performance tests	Currently planning pilot for QC applications in 2026. Hope to complete by the end of 2026.	Done in 2018 to 2024.	Sampling protocol has not changed from current practice. Testing protocols are listed in Virginia's test methods and special provision. VDOT has a special provision to be included in all maintenance contracts that started in 2023.
	– Evaluate surrogate acceptance tests correlated to design tests			
	– Develop specs/policies for pilots			
	– Conduct pilot projects			
	– Update/modify specs as needed			
Task 6: Training & Accreditation	– Develop/update BMD training and certification	Initial workshop when initial implementation. Need to revisit.	Done in 2024.	VDOT has material certification schools and BMD has been included in the curriculum since 2022. Additional webinars and training have been conducted as needed.
	– Implement statewide proficiency testing			
Task 7: Initial Implementation	– Technology transfer to industry/agency (requirements, procedures)	Continuous communication regarding changes.	Done in 2024 to 2025.	VDOT worked closely with the Virginia Asphalt Association and together they hold 2 to 3 meetings a year to communicate changes. VDOT has focused on higher traffic volume primary roads for BMD implementation.
	– Define scope and select projects			
Task 8: Full Implementation	– Implement BMD for all or selected state mix categories	2012 to 2016; data development through forensics began in 2002.	General practice implementation planned for 2026.	Virginia had initial BMD implementation in 2023, and full implementation in 2025. We have continued to evaluate the testing parameters and tolerances to make sure they line up with the roadway performance.

Taken together, the collected information in the second round survey shows that southeastern U.S. states are converging on a pragmatic model that keeps production acceptance anchored in feasible QA/QC verifications, introduces performance tests first for design verification, and will not scale toward BMD acceptance/pay until precision, aging protocols, and data confidence are established. LTA is widely viewed as important for cracking performance, but most agencies prefer to manage aging rigor in the design phase and use shorter conditioning, reheating procedures, or shift-factor concepts to preserve production timelines. Tiered frameworks are generally supported because they provide an implementation pathway that matches agency capability and industry readiness. Finally, the roadmap and timelines reinforce that adoption depends on three linked foundations: (1) consistent statewide data and benchmarking; (2) repeatability and inter-lab confidence; and (3) clear specification language defining how results affect decisions in design, QA, QC, and eventually payment.

Summary of the Panel Discussion on BMD Implementation in Southeast States (2025 SEAUPG Annual Meeting & Exhibits)

The 2025 Southeastern Asphalt User/Producer Group (SEAUPG) Annual Meeting & Exhibits, held in Charleston, WV, highlighted major advancements and emerging challenges across the asphalt industry, with particular emphasis on BMD implementation, AI-enabled pavement management, and innovations in performance testing in southeastern U.S. states. State DOTs provided updates on evolving specifications, materials, and BMD adoption efforts, while researchers presented new findings related to cracking and rutting tests, long-term aging protocols, and mixture performance validation. As part of the BMD session of SEAUPG meeting, a dedicated panel discussion featured representatives from five southeastern state DOTs: Chance Armstead (Alabama DOT), Derek Gaw (Tennessee DOT), Josh Bragg (Georgia DOT), Robert Semones (KYTC), and Angela Beyke (Virginia DOT). Each of these representatives shared updates on the current status, progress, and challenges associated with BMD implementation within their agencies. The following section summarizes the key feedback provided during this Southeast BMD State Implementation Panel in response to the question: “How do you feel you are in your journey of implementation? Are you well on your way, or are you just getting started?” The feedback presented here has been synthesized and refined for clarity while preserving the original meaning and intent of the panelists’ remarks.

Feedback by Robert Semones from Kentucky Transportation Cabinet

Kentucky began exploring BMD in approximately 2016. From that point, KYTC initiated a sustained effort to understand and implement BMD. The department issued a special note to contractors outlining expectations and began accumulating data through a series of experimental projects. Over approximately six years, KYTC conducted extensive testing as part of its BMD program and gradually developed separate performance criteria for PG 76-22 and PG 64-22 binders, recognizing that the two grades behave differently, particularly in Hamburg Wheel-Tracking and cracking tests.

Initial industry reaction included some pushback, especially regarding proposed CT Index thresholds derived from practices in other states. KYTC reassured contractors that during this developmental phase, there would be no penalties, emphasizing that the goal was collaborative learning and data collection. Contractors were encouraged to provide their best mix designs so that the agency could evaluate Hamburg and IDEAL-CT performance across a wide range of mixtures.

Kentucky now categorizes mixtures into three classes: Class 2, Class 3, and Class 4, using a single gyration level (N = 65) with a 3.5% air-void target. Volumetric properties were used to establish an initial comfort zone, after which Hamburg and IDEAL-CT tests were conducted to evaluate performance. The agency has observed strong results in both laboratory and plant-produced mixtures. For PG 64-22 mixes, KYTC initially targeted a CT Index of at least 70. Although contractors were initially concerned about achieving this value, adjustments to JMFs, particularly during winter, proved effective. Current laboratory CT values commonly fall in the 150 to 170 range, and plant-produced mixtures have achieved CT values in the 230 to 300 range (PG 64s), demonstrating significant improvement and confirming the feasibility of BMD implementation in Kentucky.

Feedback by Chance Armstead from Alabama DOT

Alabama DOT would be “neck deep” with Approach D if the state could figure out how to pay for it. That has been the agency’s big holdup. It wants to go to two performance tests, cracking and rutting, the HT-IDT and the IDEAL-CT. However, the agency does not want an interstate mix on low-volume roads. That has been the biggest holdup for the past two or three years. As the home of NCAT, Alabama DOT wants to be the first to fully implement Approach D, but figuring out how to pay for it is quite a challenge.

Feedback by Derek Gaw from Tennessee DOT

In terms of status, Tennessee DOT would say that even though it has been discussing these things for a while, it still feels like we are in the very early stages. Just a couple of weeks ago, in November 2025, Tennessee DOT placed validation test sections on a roadway, which is considered a good first step. The department has all those mixtures on the design side, and then, on the actual plant mix afterwards, has those characterized.

Tennessee still uses Marshall, so that is another very unique challenge to the state, in that most of the tests coming along are for six-inch specimens. Gyratory compactors are pretty scarce around the state. So, when Tennessee DOT staff talk about equipment being a barrier, it is not only an equipment barrier; knowledge and training among mix designers are also steps in that process. Along those lines, the industry partners of Tennessee DOT are looking at a version of BMD using Marshall. They have been doing due diligence with that, along with any benchmarking the department has been doing. They are looking at it all, so they now have the data to make that decision at each point.

Feedback by Josh Bragg from Georgia DOT

Georgia DOT has not really decided. The agency is still trying to figure out the cracking test. GDOT was looking at IDEAL-CT. However, there have been some variations with that. There has been a bit of a holdup in the industry as well, and there are some concerns with IDEAL-CT. GDOT has always been a performance-related state, so the agency conducts Hamburg testing. GDOT uses traffic- and temperature-related grades. The agency has found ways to look at this so that the design phase is volumetric, whereas it does not really focus on volumetrics in the field. GDOT is still trying to figure out the cracking test and go from there.

Feedback by Angela Beyke from Virginia DOT

VDOT considers itself to be in a steady state of implementation for its surface mixes that are non–polymer-modified. The agency is starting to look at its polymer-modified dense-grade mixes and benchmarking those. In terms of validation, looking at the list of all the different ways of validating, VDOT has probably done 90% of those, whether it is lab, pilot, field, accelerated testing, or different locations. The agency placed sections back in 2015 and 2016, so they have been down for about ten years. Over approximately the last 12 months, VDOT has gone back and looked at those sections in the field relative to the thresholds that it has based on the field performance.

As far as QA/QC, VDOT currently performs performance testing in production, but is using it as a go/no-go type of test. If the mix passes, the contractor is allowed to keep going; if it fails, the contractor has to look at the mix and try to see what is going on. VDOT would like to start to move toward using performance testing for acceptance and payment, but the agency does not yet know how to do that. One of the major difficulties is how to incorporate long-term aging.

Feedback Summary

The Southeast BMD State Implementation Panel reflected a spectrum of implementation levels, ranging from early-stage efforts to more developed and relatively steady, institutionalized programs. Tennessee DOT represents an early stage, having only recently placed initial validation test sections and still working through barriers associated with Marshall-based mix design, limited gyratory equipment, and training needs. Georgia DOT is in an early stage as well and is evaluating and gaining confidence in a suitable cracking test, such as IDEAL-CT. Alabama DOT is strongly interested in fully adopting Approach D with dual performance tests, yet is held back primarily by funding and system-level deployment concerns. By contrast, the Kentucky Transportation Cabinet has more extensive experience in BMD implementation, with nearly a decade of focused BMD development, established mixture classes, performance criteria for multiple PG grades, and demonstrated success in both laboratory and plant-produced mixtures. Virginia DOT appears to be at a relatively advanced stage of BMD implementation, having achieved a steady BMD implementation state for non–polymer-modified surface mixes, supported by extensive validation and long-term field data, and is now extending and refining its program for polymer-modified mixes and future performance-based acceptance and payment.

Conclusions

The review of state-based and national studies on BMD indicates substantial progress in performance-based mixture design, while also identifying overlapping research efforts, regional inconsistencies, and implementation bottlenecks that limit broad and effective adoption. Findings from the first round survey, with 36 state DOT responses, confirm that BMD-related activities are widespread, yet implementation remains highly heterogeneous across agencies, mix categories, and project scopes. This variability is further evidenced by the second round survey of southeastern U.S. states and the SEAUPG panel discussion, which collectively illustrate varying levels of readiness, resourcing, and specification maturity.

Performance-based testing as the core of the BMD framework remains the dominant research and implementation focus. Cracking tests (e.g., IDEAL-CT, I-FIT, SCB, DCT) and rutting tests (e.g., HWTT, APA, IDEAL-RT) are the primary focus of current BMD practice and have supported advances in test selection and threshold and specification development. At the same time, repeated benchmarking, calibration, and validation efforts across states, often targeting similar tests and objectives, created redundant work and fragmented threshold definitions driven by localized practice. In comparison, surface functionality metrics (e.g., friction and texture retention), despite their relevance to safety and surface-course performance, remain less frequently incorporated than cracking and rutting evaluations.

A commonly mentioned theme across surveys and state practices is the separation and different levels of development between the mix design and production QA/QC procedures. Agencies generally accept longer conditioning and more resource-intensive testing in the mix design phase, whereas QA/QC decisions require rapid, repeatable, and operationally feasible procedures under production timelines. As a result, several states limit HWTT and long-term conditioning primarily to mix design and rely on faster surrogate approaches (e.g., IDEAL-RT or HT-IDT for rutting and IDEAL-CT for cracking) for production. These choices are driven not only by technical considerations but also by operational constraints such as laboratory capacity, staffing, specimen preparation burden, and turnaround time under production conditions.

A few states (e.g., Oklahoma and Virginia) conducted variability and sensitivity studies that have generated valuable evidence on within- and between-lab precision, inter-laboratory repeatability, and production variability. Nevertheless, these statistical findings have not yet been effectively translated into enforceable, feasible, and defensible QA/QC acceptance criteria or specification-level limits, risk-balanced pay-factor strategies, and practical testing frequencies. This challenge is reflected in the southeastern U.S. state survey results, where performance tests are generally not yet integrated into acceptance or pay-factor frameworks, largely due to uncertainty in how to apply pay adjustments and insufficient studies and confidence in cracking-related measures during production.

Aging protocols remain both a research gap and an implementation constraint. While short-term aging (often two to four hours) is widely used as a baseline and is more commonly applied in the mix design phase, long-term aging procedures are inconsistent across states and are rarely feasible for routine production QA/QC due to time demands. A field-calibrated long-term aging (LTA) protocol remains a pressing need for effectively reflecting regional climate and mix-type effects. Many state agencies prefer rigorous aging in the design phase while exploring production-feasible alternatives, including reheating strategies and shift-factor concepts to approximate LTA effects without disrupting construction schedules. Related issues, such as lag/dwell time requirements and handling/reheating protocols, remain under-standardized and are recognized as contributors to variability that require clearer guidance.

Overall, the synthesis indicates that effective BMD implementation depends on both technical specification development and institutional readiness, including training and certification, inter-laboratory proficiency, equipment access, and clear specification language defining how results influence decisions in design, QA/QC, and ultimately payment. Progress in framework development, QA/QC integration, and field validation demonstrates that many agencies have advanced beyond pilot efforts toward early implementation. The emerging AASHTO “tiered” framework is broadly viewed as a practical pathway to phase in performance governance and guide progressive volumetric relaxation, but most agencies emphasize that greater flexibility should follow the solid establishment of validated performance criteria, aging protocols, and variability-aware QA/QC procedures. Additionally, RAP/RAS incorporation and the use of modifiers and additives remain important but comparatively underdeveloped areas requiring continued research and structured implementation planning. Coordinated regional and national actions could harmonize core practices, reduce redundancy, and promote the transition from conceptual frameworks toward implementable and performance-linked specifications.

Recommendations

Based on the findings from the literature review and two-round survey, the following strategic recommendations are proposed to guide regional and national coordination in Balanced Mix Design (BMD) implementation:

- Establish regional benchmarking and harmonized protocols for key performance tests. Develop regional reference distributions and benchmarking databases for core tests (e.g., IDEAL-CT, HWTT, IDEAL-RT), along with more consistent specimen preparation and conditioning protocols, including reheating and handling, to reduce duplication and improve comparability. Use these distributions to support consistent, data-driven threshold development while allowing documented climate- and mix-type adjustments where justified.
- Advance variability-aware specification implementation by translating existing precision and reproducibility findings into variability-aware acceptance criteria, including COV-based control limits, risk-balanced pay schedules, and clearly defined QA/QC testing frequencies. If appropriate, specify decision rules for "information-only," "go/no-go," and "pay-affecting" stages to support phased adoption and to manage risk during early implementation. Establish a regional or multi-state round-robin and proficiency testing program for priority performance tests, including standard check mixes, control charts, and periodic verification intervals. Define minimum laboratory qualification requirements and provide guidance for addressing bias/precision issues prior to linking results to acceptance or payment.
- Develop a practical, field-calibrated aging (especially LTA) framework and implementation guidance. Create a standardized and practical LTA matrix linking short-term and long-term laboratory conditioning to field aging, including climate- and mix-type considerations. Incorporate time-feasible QA surrogates (e.g., reheating/shift-factor approaches, predictive relationships) that approximate LTA effects without compromising production turnaround. Provide explicit guidance on when rigorous aging is required (e.g., design) versus when surrogates are acceptable (e.g., production), including limitations and documentation requirements.
- Standardize production sample handling, lag/dwell time, and reheating guidance. Because handling practices are identified as a contributor to variability, develop recommended or standard requirements for sample collection location, cooling/holding, maximum lag time, dwell time, reheating limits, and specimen conditioning. Align these requirements

with practical production realities to reduce avoidable variability and improve lab-to-field consistency.

- Link BMD to Pavement Mechanistic-Empirical Design and conduct end-to-end ME/FlexPAVE integration pilots with pavement management system (PMS) feedback. These efforts should explicitly link mixture performance indices and thresholds to structural design parameters (e.g., ME/FlexPAVE) and, if possible, calibrate/validate transfer functions using field performance monitoring and PMS data. These pilots should produce implementable guidance for connecting BMD outcomes to structural design decisions and network-level performance tracking.

- Integrate surface functionality into BMD implementation. Expand BMD frameworks to include friction and texture performance measures, particularly for surface mixes, OGFC, SMA, and thin overlays, addressing both initial functionality and retention over time. Prioritize development of practical laboratory or field surrogate metrics and acceptance-ready procedures where feasible.

- Design QA/QC frameworks around operational feasibility and tiered implementation. Explicitly recognize that QA/QC testing is constrained by conditioning requirements, turnaround time, testing frequency, laboratory capacity, staffing, and equipment availability. Provide tiered implementation pathways, aligned with the AASHTO tier framework, allowing states to adopt performance testing progressively (e.g., information-only → acceptance → pay) and use surrogate tests in production where full test suites are impractical, while maintaining technical defensibility.

- Establish standardized decision frameworks for RAP/RAS, modifiers, and additives. Develop decision frameworks that link recycled material content, modifier selection, and additive type to validated performance outcomes, including required verification testing, variability, and field monitoring requirements. Where possible, incorporate life-cycle cost analysis (LCCA) and sustainability metrics to support balanced decision-making without compromising durability.

- Define a stepwise volumetric relaxation framework tied to demonstrated performance. Introduce flexibility only after core elements, workable performance specifications, validated aging protocols, and feasible QA/QC procedures are well established and supported by sufficient statewide or regional evidence.

- In summary, while significant advancements have been made, the path toward full BMD implementation requires coordinated regional and national actions emphasizing standardization, data-driven QA/QC, operational feasibility, and mechanistic design integration. By strengthening benchmarking, variability governance, aging standardization, surface functionality evaluation, and implementation decision frameworks, SASHTO agencies can accelerate the transition toward a robust, performance-based, and sustainable pavement design and infrastructure management system.

Acronyms, Abbreviations, and Symbols

Term	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Content
ADT	Average Daily Traffic
ANOVA	Analysis of Variance
APA	Asphalt Pavement Analyzer
APT	Accelerated Pavement Testing
ASTM	American Society for Testing and Materials
AV	Air Voids
BBF	Bending Beam Fatigue
BMD	Balanced Mix Design
COV	Coefficient-of-Variation
DCT	Disk-Shaped Compact Tension (Test)
DFT	Dynamic Friction Tester
DOT	Department of Transportation
ESAL	Equivalent Single-Axle Load
FAM	Asphalt Fine Aggregate Matrix
FHWA	Federal Highway Administration
FMFC	Field-Mixed Field-Compacted
FMLC	Field-Mixed Laboratory-Compacted
FN	Flow Number Test
FTIR	Fourier Transform Infrared Spectroscopy
FWD	Falling Weight Deflectometer
GAS	Global Aging System
GTR	Ground Tire Tubber
HP-GPC	High-Pressure Gel Permeation Chromatography
HPTO	High-Performance Thin Overlay

Term	Description
HWTT	Hamburg Wheel-Tracking Test
IDEAL-CT	Indirect Tensile Asphalt Cracking Test
IDEAL-RT	Indirect Tensile Asphalt Rutting Test
IDT	Indirect Tensile Strength
I-FIT	Illinois Flexibility Index Test
IWG	Implementation Working Group
KYTC	Kentucky Transportation Cabinet
LADOTD	Louisiana Department of Transportation and Development
LCCA	Life-Cycle Cost Analysis
LMLC	Laboratory-Mixed Laboratory-Compacted
LTA	Long-Term Aging
LTOA	Long-Term Oven Aging
LTRC	Louisiana Transportation Research Center
LWT	Loaded Wheel Tester
ME	Mechanistic–Empirical
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal Maximum Aggregate Size
OGFC	Open-Graded Friction Course
OT	Overlay Test
PAV	Pressure Aging Vessel
PEP	Performance Engineered Pavements
PMFC	Plant-Mixed Field-Compacted
PMLC	Plant-Mixed Laboratory-Compacted
PMS	Pavement Management System
PRS	Performance-Related Specifications
QA	Quality Assurance
QC	Quality Control
RAP	Reclaimed Asphalt Pavement

Term	**Description**
RAS	Reclaimed Asphalt Shingles
RLT	Repeated Load Triaxial Test
SASHTO	Southeastern Association of State Highway and Transportation Officials
SBS	Styrene-Butadiene-Styrene
SCB	Semi-Circular Bend (Test)
SEAUPG	Southeastern Asphalt User/Producer Group
SHAs	State Highway Agencies
SIP	Stripping Inflection Point
SMA	Stone Mastic Asphalt
STA	Short-Term Aging
STOA	Short-Term Oven Aging
S-VECD	Simplified Viscoelastic Continuum Damage
TBT	Texas Boiling Test
TSR	Tensile Strength Ratio
UV	Ultraviolet
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
VTM	Voids in the Total Mixture
cm	centimeter(s)
ft.	foot (feet)
in.	inch(es)
lb.	pound(s)
m	meter(s)

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Appendix

Table A1. Summary of BMD implementation across U.S. states based on Regional Peer Exchange on Balanced Mix Design

BMD Approach	State	Testing		Testing Standard	Aging	Test Criteria	Test Utilization and Consistency
Approach A	AL	R	Hamburg HT-IDT	AASHTO T 324 ALDOT 458	Hamburg and HT-IDT: AASHTO R30 2 hr @ 135°C	Hamburg: Mixes with 67-22 Binder < 10mm at 10,000 passes Mixes with 76-22 binder < 10mm rutting at 20,000 passes HT-IDT: TBD	Rutting NOT tested during acceptance.
		C	IDEAL-CT	ASTM D8225-19	AASHTO R 30 2 hr @ 135°C	TBD : ESAL Range A/B: 50 ESAL Range C/D: 75 ESAL Range E: 100	Cracking NOT tested during acceptance.
		M	TSR HWTT	AASHTO T 283 AASHTO T324	N/A	TSR : 0.80 HWTT: Mixes with 67-22 Binder < 10mm at 10,000 cycles. Mixes with 76-22 binder < 10mm rutting at 20,000 passes.	TSR is used for design and acceptance.
Approach A	LA	R	HWTT	AASHTO T324	AASHTO R30 –STA 4 hr	Lv 2: (high traffic) <6mm @ 20,000 passes Lv 1: (low traffic) <10mm @ 20,000 passes	Must pass prior to production. Verified during production.
		C	SCB-Jc	ASTM D8044	AASHTO R30 –LTA 5 days – 85°C	Lv 2: (high traffic) Jc>0.6 kJ/m2 Lv 1: (low traffic) Jc>0.5 kJ/m2	Must pass prior to production.
		M	HWTT	AASHTO T324	AASHTO R30 –STA	No stripping inflection point.	Must pass prior to production. Verified during production.
Approach A	PA	R	HWTT	-	-	-	Same test used during mix design and acceptance.
		C	IDEAL CT	-	-	-	
		D/M	TSR	-	-	-	
Approach A	AZ	R	HWTT	AASHTO T 324	2 hr	-	-
		C	IDEAL CT	ASTM D8225	2 hr	-	-
		D/M	IMC	Arizona Test Method 802	2 hr	-	-
Approach A	WA	R	WSDOT Hamburg Wheel-Track Testing	FOP for AASHTO T 324	4 hr at 135˚C. Currently working on new temperature and time specification for aging that reflects 5-7 years of pavement performance.	Minimum Number of Passes with no Stripping Inflection Point and Maximum Rut Depth of 10 mm at: < 0.3 ESAL’s - 10,000 Passes 0.3 to < 3 ESAL’s - 12,500 Passes ≥ 3 ESAL’s - 15,000 Passes	NOT same test used during mix design and acceptance.
		C	WSDOT Indirect Tensile (IDT) Strength (psi)	FOP for ASTM D6931	Same as rutting	175 psi maximum all classes of mix	
		D/M	WSDOT Hamburg Wheel-Track Testing	FOP for AASHTO T 324	Same as rutting	See rutting specification	
Approach A	IL	R	IL-modified HWTT	IL-modified AASHTO T 324	If WMA produced at temps. 275 +/- 5°F or less, loose mix aged at 270 +/- 5°F for 2 hr.	≤ 12.5mm of Rut Depth at a Minimum number of Wheel Passes based on PG Asphalt Grade and Mix Type if 4.75mm NMAS	Same test used during mix design and acceptance.
		C	IL-modified I-FIT	IL-modified AASHTO T 393	Semi-Circular Test Specimens Aged in 95˚C Oven for 72 hrs.	STA Flexibility Index ⩾ 8.0; LTA criteria for Design of 5.0 and 4.0 for Production Mix. FI of 16.0 for SMA (10.0 for LTA SMA) and 12.0 for 4.75 mix. (LTA criteria only for surface mixtures).	

		D/ M	IL-modified TSR	IL-modified AASHTO T 283	None, water bath 60˚C, no freeze/thaw cycle(s) and no saran wrap and plastic bag.	TSR ≥ 0.85 (150 mm dia. specimens) Minimum Conditioned Strength of 60 psi for non-polymer mixes 80 psi for polymer modified mixes Minimum of 70 psi for PG 64-28 or lower (softer) asphalt binders.	
Approach A	**MI**	**R**					
		C					
		D/ M	TSR	AASHTO T 283		80% minimum.	No, not needed for acceptance.
Approach A	**MN**	**R**	HWTT	AASHTO T 324	2 hr?	Depending on traffic level of mix specified.	Mix Design Only
		C	DCT/IDEAL	Marasteanu et al., 2012 ASTM D8225	2 hr?		
		D/ M	HWTT	AASHTO T 324	2 hr?		
Approach A (considering B & C)	**OH**	**R**	APA (current) HWTT (evaluating and a rutting rapid test for QC)	AASHTO T 340 slightly modified	AASHTO R 30 for STOA for 4 hr at 275°F for mix design acceptance.	Most designers design for 15% max therefore the test is rarely used. < 5.0 mm for PG 58-28 and PG 64-22 mixes tested at 120 deg F < 3.0 mm for all other mixes tested at 130 deg F.	Same test used during mix design and acceptance looking at research to find a quicker test.
		C	IDEAL-CT	ASTM D8225-19 modified	AASHTO R 30 for STOA for 4 hr at 275°F for mix design acceptance. Plant mix: Allow to cool then reheat at compaction temperature for 2.5 to 3 hr.	Surface mixes: Min of 80 12.5 mm Intermediate: Min of 70 Other intermediates and base: Min of 60	The plan is to use the same test but currently haven't used the test in mix design yet. To reevaluate plant produced materials and how we would accept reheat mix, heat up procedure, etc.
		D/ M	TSR (current) HWTT (evaluating)	AASHTO T 283 modified	Loose mix aged for 4 hr at 275 deg F. Then heat loose mix to required compaction temp.	All heavy traffic mixes (Superpave): Min of 0.80 Other mixes (containing gravel): Min of 0.70. This is changing as we're requiring antistrip and the min would change to 0.80.	
Approach A	**SD**	**R**	APA	AASHTO T 340	No	APA Max. Rutting: 5 to 8 mm depending on the type of mix (run @ high PG binder temp)	Mix Design Only.
		C	N/A (evaluating IDEAL CT test)				
		D/ M	SD309	AASHTO T 245 / ASTM D4867	Compaction temp for 2 hr prior to compaction (1 hr for field samples).	TSR = 80% minimum (70% min. for Class G mixes)	Mix Design Only – waived if 1.00% hydrated lime is added.
Approach A & B	**MA**	**R**	HWTT	AASHTO T 324	AASHTO R 30 Short-term aging	<12.5 mm after 20,000 passes combined with No SIP before 15,000 passes	Same test used during mix design and acceptance.
		C	IDEAL-CT	ASTM D 8225	20 hr at 100 degrees C	>= 90	
		D/ M	HWTT	AASHTO T 324	AASHTO R 30 Short-term aging protocol	<12.5 mm after 20,000 passes combined with No SIP before 15,000 passes	
Approach A (Pilot Projects) & B (STIC Research Project)	**NH**	**R**	IDEAL-RT (STIC research) HWT (SMA Pilot)	ASTM D8360-22 AASHTO T 324–22		SMA Pilot: HWT: Average rut depth, 10.0 mm maximum at 20,000 cycles SIP, passes 15,000 min	Mix Design only, not for acceptance.
		C	IDEAL-CT (STIC research SMA Pilot)	ASTM D8225		>=175	
		D/ M	TSR	AASHTO T 283		>0.8	
Approach A & B	**NJ**	**R**	APA	AASHTO T 340	AASHTO R 30 Short-term aging	Varies by mix.	Same test used during mix design and acceptance.
		C	Overlay	Tex-248-F	AASHTO R 30 Short-term aging		Same test used during mix design and acceptance.
		D/ M	TSR	AASHTO T 283	AASHTO R 30 Short term aging		Test only used during Mix Design.

Approach A & B	**CO**	**R**	HWTT		No	Max of 4mm after 10,000 passes	
		C	IDEAL CT		No, but investigating options.	Still determining	
		D/ M	HWTT		No	Max of 4mm after 10,000 passes	
Approach A & B	**IN**	**R**	HWTT	AASHTO T 324	AASHTO R 30, 4 hr conditioning	N/A	
		C	IDEAL-CT	ASTM D8225	AASHTO R 30, 4 hr conditioning	N/A	
		D/ M	Cantaboro TSR	AASHTO TP 108 AASHTO T 283	AASHTO R 30, 4 hr conditioning	N/A 80% min for HMA 70% min for SMA	
Approach A & B	**WY**	**R**	HWTT IDEAL-RT	AASHTO T 324 ASTM D8360			
		C	IDEAL-CT	ASTM D8225		TBD	
		D/ M	TSR	AASHTO T 283		75% minimum TSR	Same test used during mix design and acceptance.
Approach A, B, & C	**VT**	**R**	HWTT		R30	½” at 20000 passes (going into effect ~2024)	Test used for Mix Design only, we are not considering it for acceptance program wide.
		C	IDEAL CT	ASTM D8225-19	R30	No Criteria, data reporting only	
		D/ M	HWTT		R30	SIP at 15000 (going into effect ~2024)	
Approach A, B, & C	**NV**	**R**	Hveem Stability		16 hrs 60°C	High Traffic =37 Medium Traffic =35 Low Traffic =30	Same test used during mix design and acceptance.
		C	Texas Overlay Tester	Tex-248-F 7% AV, 0.018”displacement	Short-term aging	PG64=2,000 cycle PG76=1,750 cycle Hveem Stability >18	For mix design only.
		D/ M	TSR	AASHTO T 283	16 hr 60°C	TSR > 70% Original TS, PG76=100 psi PG64= 65 psi	Same test used during mix design and acceptance.
Approach A, B, & C	**UT**	**R**	HWTT	T 324	2 hr, R 30	<10mm in 20K passes	Same test used during mix design and acceptance.
		C	IDEAL-CT	ASTM D8225	2 hr, R 30		
		D/ M	HWTT	T 324	2 hr, R 30	<10mm in 20K passes	Same test used during mix design and acceptance.
Approach A & C	**NY**	**R**	HT-IDT IDEAL-RT (In Evaluation) HWTT (In Evaluation)	ASTM D6931-17 ASTM D8360-22 AASHTO T 324	Lab Mixed: 4 hr aging at compaction temperature Plant Mixed: No additional aging	HT-IDT: 30 psi IDEAL-RT: No criteria set HWTT: 20,000 passes	Same test used during mix design and acceptance.
		C	Semi-Circular Bending IFIT Test IDEAL CT	AASHTO T393-21 ASTM D8225-19	Lab Mixed: 4 hr aging at compaction temperature Plant Mixed: No additional aging	Flexibility Index of 8 CT Index value of 135	Same test used during mix design and acceptance.
		D/ M	TSR	AASHTO T 283	None	>80%	Same test used during mix design and acceptance.
Approach B	**MO**	**R**	HWTT	AASHTO T 324	2 hr Lab Aging	Max. ½” Rutting @ # Passes correlating to Binder Type	Same test used during mix design and acceptance.
		C	IDEAL-CT	ASTM D8225	2 hr Lab Aging	> 100 – 3% Bonus Minimum = 45 < 45 – 3% Deduct	
		D/ M	TSR	AASHTO T 283	Cooled to room temperature and reheated for 2 hr.	>90% - 3% Bonus 75-89% -100% Pay 70-74% - 2% Deduct 65-69% - 3% Deduct <65% Remove	
Approach B	**ND**	**R**	HWTT	AASHTO T 324		>10,000 passes Water 46 C	
		C	IDEAL-CT DCT	ASTM D8225 Marasteanu et al., 2012	4 hr at 135 C	Not established	
		D/ M	HWTT	AASHTO T 324		>8000 passes Water 46 C	

Approach B & C	**OR**	**R**	HWTT		R 30 short-term only	7mm @ 20,000 passes at 50 C	
		C	IDEAL-CT	ASTM D8225	Long-term 24 hr at 95°C	Not chosen	
		D/ M	Modified Lottman/ Hamburg			80% TSR for mix design No SIP at 15,000 passes	
Approach B & C	**TX**	**R**	HWTT IDEAL-RT	Tex-242-F ASTM D8360	2 hr short-term oven aging at compaction temperature.	HWTT, Max 12.5mm rut: @ 10,000 for PG 64. @ 15,000 for PG 70. @ 20,000 for PG 76. IDEAL-RT: 60 for PG 64 or lower. 65 for PG 70. 75 for PG 75 or higher.	Same test used during mix design and acceptance.
		C	Texas OT IDEAL-CT	Tex-248-F; Tex-250-F	2 hr short-term oven aging at compaction temperature.	Texas OT: CFE > 1. CPR < 0.45. IDEAL-CT: 80 for PG -22 or higher. 100 for PG -28 or lower.	
Approach B, C & D	**MT**	**R**	Hamburg		2 hr per R 30 for volumetric testing (simulation of plant dwell time)	½" rut max after 15,000/10,000 passes for verification and production, respectively, although these may change with our implementation of MSCR.	Same test used during mix design and acceptance.
		C	IDEAL-CT	-	6 hr at 135°C	TBD. Performing LMLC evaluations of mixes now, moving to PMLC evaluation and eventually shadow projects for benchmarking.	
		D/ M	TSR (Potentially Hamburg)		Standard for TSR	70% ratio, min.	
Approach B & D	**OK**	**R**	HWTT	AASHTO T 324	AASHTO R30 – 2 hr aging	12.5 mm max, 10, 15 or 20K passes depending on PG grade.	Only run for mix design acceptance.
		C	IDEAL-CT	ASTM D8225	4 hr aging	CT Index: 100 Surface 60 Intermediate	Only for mix design acceptance. Will evaluate field testing with 2024 implementation projects.
		D/ M	TSR	AASHTO T 283	2 hr aging	0.80 Design 0.75 Field	Same test used during mix design and acceptance.
Approach C	**GA**	**R**	HWTT	AASHTO T324		PG 64-22 & PG 67-22, 4.75 mm, 9.5 mm SP Type I, and Type II, ≤ 12.5 mm, 15,000 passes, SIP > 15,000 Passes PG 64-22 and PG 67-22, 12.5 mm SP, 19 mm SP and 25 mm SP, ≤12.5 mm, 20,000, SIP > 20,000 Passes PG 76-22, All Mix types, ≤ 12.5 mm, 20,000, SIP> 20,000 Passes.	
		C	IDEAL-CT	ASTM D8225		State Routes (Non-controlled access) <10,000 ADT, 4.75 mm and All Superpave Mix Types: ≥ 50. State Routes (Non-controlled access) ≥10,000 ADT, All Superpave Mix Types: ≥ 70. Interstates and Controlled Access State Routes, All Superpave Mix Types: ≥ 100. Interstates and Controlled Access State Routes, All SMA Mix Types: ≥ 150.	
		M	TRS	AASHTO T 283		>0.8 >0.7 for if all individual strength values > 100 psi.	
Approach C	**WI**	**R**	HWTT	AASHTO T 324	STA of 4 hr for lab mixed. NONE for plant mixed.	The minimum number of passes to failure (or rut depth of 12.5 mm) depending on the binder designation: S (10,000 passes), H (15,000 passes), V (20,000 passes), and E (20,000 passes).	Same test used during mix design and acceptance.

						The minimum number of passes to reach SIP is 8,000.	
		C	IDEAL-CT	ASTM D8225	6 hr long-term aging.	Minimum 30 for dense-graded and 80 for SMA mixtures.	
		D/ M	HWTT	AASHTO T 324	STA of 4 hours for lab mixed. NONE for plant mixed.	The minimum number of passes to reach SIP is 8,000.	
Approach C	**CA**	**R**	HWTT (Non-PRS)	AASHTO T 324 / California Test 389 (Non-PRS)	Design verification is based on plant-produced asphalt mixtures. No additional laboratory aging is specified.	Number of Wheel Passes at 0.5-inch Rut Depth: PG 58: ≥ 10,000 (Type A), ≥ 15,000 (RHMA-G) PG 64: ≥ 15,000 PG 70: ≥ 20,000 PG 76 or higher	For mix design.
			RLT (PRS)	AASHTO T 378 (modified) (PRS)		Permanent Deformation:1,2 Minimum number of cycles to 3% permanent axial strain at 122˚F. HMA-LL Surface: 941 HMA-LL Intermediate	For mix design.
		C	Non-PRS: None PRS: FBF & I-FIT (PRS) IDEAL-CT (evaluating)	Non-PRS None PRS AASHTO T 321(modified)	Design verification is based on plant-produced asphalt mixtures. No additional laboratory aging is specified.	Beam stiffness (ksi): 2,5 Minimum stiffness at the 50th cycle at the given testing strain level. 210 at 893*10-6 inch/inch (Surface) 782 at 433*10-6 inch/inch (interm.) 707 at 420*10-6 inch/inch (rich bottom) Beam fatigue: Minimum of 1,000,000 cycles to failure at this strain. 495*10-6 inch/inch (Surface) 220*10-6 inch/inch (interm.) 269*10-6 inch/inch (rich bottom) Minimum of 250,000 cycles to failure at this strain: 893*10-6 inch/inch (Surface) 443*10-6 inch/inch (interm.) 420*10-6 inch/inch (rich bottom)	For mix design.
			PRS: I-FIT	AASHTO TP 124.		Semicircular beam fracture potential:2 Minimum flexibility index (FI): 3.0 (Surface) 0.5 (interm.) 0.5 (rich bottom)	
		D/ M	Non-PRS: Tensile strength (TS) HWTT PRS: HWTT	Non-PRS: AASHTO T 283. PRS: California Test 389		Moisture Sensitivity: Minimum repetitions for rut depth of 0.5 inch at 122˚F. 20,000 (surface and intermediate)	For mix design
Approach C & D	**NM**	**R**	HWTT	AASHTO T 324			
		C	IDEAL-CT (Texas OT SCB)	ASTM D8225 (Tex-248-F ASTM 8044)			
Approach C & D (hybrid)	**AR**	**R**	APA	AHTD 480	AASHTO R 30 2-hr @ compaction temp.	Two 150mm by 75mm specimens; 100 psi hose pressure; 8000 cycles.	Rutting NOT tested during acceptance.
		C	IDEAL-CT	ASTM D8225-19	AASHTO R 30 4 hr @ 135°C		In verification process and QA for information only.
		M	Retained Stability	Modified T245	None	100i hose pressure; 8000 cycles.	Used for mix verification during first 90 days of production.
Approach D	**TN**	**R**	HWTT	AASHTO T324	AASHTO R30 2 hr	<12mm rutting @ 50C Min passes req'd changes by road AADT. (10/15/20k)	Probably different tests used for mix design and acceptance. Evaluating for a quick test for acceptance
		C	IDEAL-CT	ASTM D8225	AASHTO R30 4 hr	< min 50/75/100 Depending on road AADT. Considering a peak load requirement.	Probably IDEAL-CT for mix design and acceptance.

		M	HWTT	AASHTO T324	AASHTO R30 2 hr	SIP may occur but only beyond 10k passes, all roads.	Probably different tests used for mix design and acceptance. TSR
		F	DFT (TBD)	ASTM E1911	TBD	Research underway. Most likely some level of friction achieved at a design polishing with a Three Wheel Polisher.	N/A
Approach D	**ID**	**R**	HWTT	AASHTO T 324	AASHTO R 30	<10.0 mm @ 15,000	Same test used during mix design and acceptance.
		C	IDEAL CT	ASTM D8225	AASHTO R 30	> 80 (information only at this time)	
		D/ M	HWTT	AASHTO T 324	AASHTO R 30	No stripping inflection point (SIP) @ 15,000	
TBD	**MS**	**R**	TBD (APA, HWTT, IDEAL-RT, and HT-IDT)	TBD	AASHTO R 30 STA 2 hr		IDEAL-RT or HT IDT for production.
		C	IDEAL-CT	ASTM D8225-19	AASHTO R 30 STA 2 hr		IDEAL-CT during mix design and acceptance.
		M	Hamburg Cantabro	AASHTO T324 AASHTO TP 108-14	AASHTO R30 STA 2 hr		Both for mix design and possibly Cantabro for production.
TBD	**ME**	**R**	HWTT (Implemented) IDEAL-RT (Investigating)	AASHTO T 324–22 ASTM D8360-22	Lab produced (rarely used): STA procedure in R 30 (135°C for 2 hr)	Rut Depth < 12.5 mm at 20,000 passes # Passes >= 20000 45°C for 64-28 48°C for 64E 50°C for asphalt rubber or 70E	Primarily just design approval.
		C	IDEAL-CT (Investigating)	ASTM D8225	Lab produced (rarely used): STA procedure in R 30 (135°C for 2 hr) Considering long-term/critical aging options.	Preliminary criteria of CT Index <= 150 on reheated plant-produced or 2 hr aged lab-batched material	Not implemented but unlikely for acceptance.
		M	HWTT	AASHTO T 324 – 22	Lab produced (rarely used): STA procedure in R 30 (135°C for 2 hr)	SIP >= 15,000 passes 45C for 64-28 48C for 64E 50 C for asphalt rubber or 70E	Primarily just design approval.
TBD	**NE**	**R**	IDEAL-RT	ASTM D8360-22	NCAT Protocol		
		C	IDEAL-CT	ASTM D8225			
		D/ M	TSR	AASHTO T 283			
States where BMD implementation status is included.				AK, CT, DE, FL, HI, IA, KS, KY, MD, NC, RI, SC, VA, WV			
Note:							
🟩: **SASHTO States** **R**: rutting **C**: cracking **M**: moisture **F**: friction		**APA**: Asphalt Pavement Analyzer **HWTT**: Hamburg Wheel-Tracking Test **IDT**: Indirect Tensile Test **HT-IDT**: High-Temperature Indirect Tensile Test **IDEAL-CT**: Indirect Tensile Asphalt Cracking Test **IDEAL-RT**: Indirect Tensile Asphalt Rutting Test **ITS**: Indirect Tensile Strength **IMC**: Index for Moisture Condition **OT**: Overlay Tester				**RLT**: Repeated Load Triaxial **FBF**: Fatigue Beam Fatigue **DFT**: Dynamic Friction Tester **TSR**: Tensile Strength Ratio **ST**: Tensile Strength **I-FIT**: Illinois Flexibility Index Test **SCB-Jc**: Semi-Circular Bend Test **DCT**: Disk-Shaped Compact Tension Test	

Table A2. Completed and ongoing state-based projects and research.

State	Study Date	BMD-Related Key Words	BMD-Related Projects and Studies
VT	Oct. 2024	Inter-laboratory Study, performance tests, HWTT, I-FIT, IDEAL-CT.	*Project*: Inter-Laboratory Study (ILS) of Bituminous Concrete Balanced Mix Design (BMD) Tests for Use on VTrans Projects
	Feb. 2022	Sensitivity, binder source, production variation.	*Journal Paper*: Implementation Considerations of Balanced Mix Design in Practice: Recent Experience in Vermont
	Nov. 2023	Asphalt mixture performance tests, HWTT, I-FIT, IDEAL-CT.	*Journal Paper*: Balanced Mix Design Benchmarking of Asphalt Mixtures Produced in Vermont
	Nov. 2023	Plant-produced mixture, production variability between sublots and sources.	*Journal Paper*: Balanced Mix Design Production Analysis of Asphalt Mixtures in Vermont
VA	Sept. 2025	Documenting full statewide BMD implementation, QA/QC data, adjustments/improvements to the specification, all SM-9.5, a white paper for future reference, SM-12.5 A and D surface mixes.	*Ongoing Project*: Documentation of 2024 Balanced Mix Design Implementation
	Jun. 2025	Filed validation of BMD test criteria, FWD, asphalt content, gradation, mixture testing, recovered binder properties.	*Ongoing Project*: Field Validation of Balanced Mix Design Initial Criteria
	Jul. 2026	BMD framework, SBS modified dense-graded asphalt surface mixtures, high polymer modified asphalt mixtures, cracking resistance test.	*Ongoing Project*: Developing a Balanced Mix Design (BMD) Framework for SBS Modified Dense-Graded Asphalt Surface Mixtures—Phase I
	Mar. 2026	Reheating effects and isolation, impact on volumetric properties, dense-graded (A and D designations), BMD field trials, entity differences (producer, district, VTRC), mix batch differences.	*Ongoing Project*: Evaluating the Impact of Volumetric Properties and Reheating on the Balanced Mix Design Test Results
	Dec. 2023	Fiber-reinforced materials, pavement performance, tensile strength, using data from two pilot projects.	*Project*: Balanced Mix Design for Surface Asphalt Mixtures—Fiber-Modified Mixtures
	Dec. 2023	High RAP (up to 45%), recycling agent, rutting, cracking, durability, performance tests, APT, heavy vehicle simulator.	*Project*: Evaluation of Balanced Mix Design (BMD) Surface Mixtures with Conventional and High RAP Contents under Laboratory-Scale and Full-Scale Accelerated Pavement Testing (APT)

	Jan. 2025	Practical long-term aging protocols, IDEAL-CT, preliminary threshold, dense-graded (A and D designation), reheated plant-produced mixtures, mix design verification, QA/QC.	*Project*: Developing Long-term Aging Protocols for Cracking Performance Evaluation of Asphalt Mixtures in Virginia
	Jun. 2024	Performance-based threshold criteria, a pool of representative asphalt mixtures, correlation between empirical test results and fundamental tests, surrogate indices, Mechanistic-Empirical (ME) design, performance thresholds refinement.	*Project*: Mechanistic-Based Evaluation of Performance Thresholds for Engineered Surface Asphalt Mixtures
	Mar. 2023	Field trials, plant production, performance testing, high RAP contents, APA rut test, Cantabro test, IDEAL-CT.	*Project*: Balanced Mix Design for Surface Mixtures—2020 Field Trials
	Jun. 2021	Field trials, plant production, performance testing, APA rut test, Cantabro test, IDEAL-CT.	*Project*: Balanced Mix Design for Surface Asphalt Mixtures—2019 Field Trials
	Jun. 2023	Pilot projects, plant production, performance testing, APA rut test; Cantabro test, IDEAL-CT, QA/QC, acceptance.	*Project*: Balanced Mix Design for Surface Mixtures—2021 and 2022 Plant Mix Schedule Pilots
	May 2021	Initial roadmap, specification verification, performance testing, APA rut test, indirect tensile cracking test, I-FIT test, IDT N_{flex} test, dynamic modulus, Cantabro test, CT index.	*Project*: Balanced Mix Design for Surface Asphalt Mixtures: Phase I—Initial Roadmap Development and Specification Verification
	Jun. 2023	Production variability, gradation and volumetric adjustment, IDT-CT; APA; Cantabro Mass Loss, variability, plant production.	*Project*: Impact of Production Variability on Balanced Mix Designs in Virginia
	Jan. 2023	Rutting performance testing, alternative tests, HT-IDT, IDEAL RT, rapid rutting test, rutting tolerance index, APA, performance criteria.	*Project*: Simple and Practical Tests for Rutting Evaluation of Asphalt Mixtures in the Balanced Mix Design Process
LA	Mar. 2021	Case studies, BMD implementation, selection of performance test, SCB, LWT, field performance relationship, inter-laboratory study, training and certification.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures: Louisiana Department of Transportation & Development (DOTD)
	Mar. 2024 to Mar. 2025	Literature review, the efficacy of IDEAL-CT and IDEAL-RT, volumetric properties, field vs. laboratory Performance, LWT, SBC, aging, QA/QC.	*Project*: Literature Review of IDEAL-CT and IDEAL-RT Test Methods for Balanced Mixed Design
	Jun. 2024	QC/QA; SCB J_c; scaling factor; long-term aging; cracking resistance; rheology; chemistry.	*Project*: Implementation of Semi-Circular Bend (SCB) Test for QC/QA of Asphalt Mixtures
	Jul. 2019	RAP/RAS, low, intermediate, and high service temperatures binder and mixture tests, LWT, SCB.	*Project*: Evaluation of Asphalt Mixtures Containing Recycled Asphalt Shingles

	Apr. 2011 to Sept. 2014	QC/QA, Performance-Based Specification, a PBS implementation framework for LA, performance metrics, SCB, LWT, IDT, performance criteria, LA-PMS, calibration with 20-year projected distresses.	*Project*: Development of Performance-Based Specifications for Louisiana Asphalt Mixtures
GA	Apr. 2022	Corrected Optimum Asphalt Content; IDEAL-CT; benchmark; CT index thresholds; high RAP content mixtures.	*Journal Paper*: Evaluating Impact of Corrected Optimum Asphalt Content and Benchmarking Cracking Resistance of Georgia Mixtures for Balanced Mix Design Implementation
AL	2022	Field trial projects, IDEAL-CT, HT-IDT, acceptance, PMLC vs LMLC, correlation between performance test results and volumetric parameters.	*Field Trial Project*: Balanced Mix Design Field Trial Projects in Alabama
	2024	QA testing program, pay assessment schedules.	*Ongoing Research Project:* Evaluation of Alabama Department of Transportation's Quality Assurance Testing Program and Pay Assessment Schedules for Asphalt Mixtures
	2018 to 2021	OGFC, SMA, dense-graded thin lay mix	Phase VII (2018-2021) NCAT Test Track Findings: Alabama DOT Sections
	Apr. 2020	Rutting resistance and moisture susceptibility, HWTT, rut depth, field performance data correlations, criterion, laboratory repeatability.	*Journal Paper*: Determining the Relationship Among Hamburg Wheel-Tracking Test Parameters and Correlation to Field Performance of Asphalt Pavements
KS	Jul. 2023 to Jan. 2025	Performance-based testing, IDEAL-CT, IDEAL-RT, HWTT, RAP, RAS, acceptance, PWL/QC-QA, shadow projects, Monte Carlo simulation, recommendations for potential pilot projects, QC/QA process.	*Project*: Evaluation of Balanced Mixed Design in Kansas
CA	Oct. 2023 to Sept. 2026	Performance-related tests, performance-related specifications, integration of mix design and structural design, approval process 40% high RAP, inter-laboratory study.	*Ongoing Project*: Continued Support for Implementation of Performance-Related Tests and Specifications for Balanced Mix Design, Increased Recycling of Asphalt Mixes, and Integration of Mix Design and Structural Design
	Aug. 2018	Performance-related laboratory tests, performance-related specifications, ME pavement structural designs, mix design guidance, fatigue, stiffness, rutting resistance.	*Project*: Mechanistic-Empirical (ME) Design: Mix Design Guidance for Use with Asphalt Concrete Performance-Related Specifications

	Oct 2017 to Oct. 2020	QC/QA, fatigue performance-related test, fatigue cracking, SCB, IDEAL-CT, FAM mixes, performance-related testing, 4PB fatigue test, good correlation between IDEAL-CT and 4PB, CalME.	*Project*: Preliminary Study on Developing a Surrogate Performance-Related Test for Fatigue Cracking of Asphalt Pavements
	Mar. 2021	Case studies, LLAPs, performance-related specifications (PRS), rutting (HWTT, RLT), cracking (I-FIT, FBF), material sensitivity, field validation, and repeatability (single and multiple operator variability), allowing for more RAP, recycled plastic.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures
AR	Dec. 2022	Cracking test, aging protocols (AASHTO R30 STA combined with the NCAT LTA), IDEAL-CT, rutting, APA, IDEAL-CT similar to SCB/IFIT system.	*Project*: Performance-Based Asphalt Mixture Design (PBD) for Arkansas
	Aug. 2023	Compatibility (types of binders and aggregates), moisture resistance, max. amount of sandstone aggregates, durability, Texas Boiling Test (TBT), dynamic modulus, HWTT, I-FIT, IDEAL-CT, TSR, QC/QA.	*Project*: Effect of Aggregate-Binder Compatibility on Performance of Asphalt Mixtures in Arkansas
IN	Apr. 2020	Cracking resistance, rutting resistance, I-FIT, HWTT, S-VECD test, fatigue resistance, material quality, FlexPAVE, flexibility index, performance-related QC/QA, PMLC higher than PMFC, performance test sensitivity, modified binder.	*Project*: Quality Control and Quality Assurance of Asphalt Mixtures Using Laboratory Rutting and Cracking Tests
AZ	Oct. 2024 to Oct. 2025	Cracking resistance prediction, rutting-resistance assessments, IDEAL-RT, rutting resistance prediction.	*Project*: Assessment of Asphalt Shear Rutting Test Method to Improve the Performance of ADOT Asphalt Mixes
ID	Sept. 2020 to May 2023	RAP, recycling agent, rejuvenators, tall oil and waste vegetable oil, higher RAP content (50 or 70 percent), stiffening effect of RAP, fatigue cracking, thermal cracking, rutting.	*Project*: Implementation of Balanced Asphalt Mix Design of Asphalt Mixtures Prepared with Reclaimed Asphalt Pavements and Rejuvenators for Enhanced Performance
	May 2017 to May 2021	RAP, max allowable RAP content (from 30%), cracking resistance.	*Project*: Developing Recommendations for Allowable RAP Contents in Idaho Asphalt Mixes
	Jan. 2016 to Jun. 2018	Performance measures, performance-based mix design, RAP, monotonic cracking assessment IDT tests, SCB dynamic cracking assessment tests, rutting assessment tests, APA, HWTT.	*Project*: Development and Evaluation of Performance Measures To Augment Asphalt Mix Design in Idaho

	Dec. 2024	RAP, recycling agent, rejuvenators, tall oil and waste vegetable oil, higher RAP content (50 or 70 percent), stiffening effect of RAP, fatigue cracking, thermal cracking, rutting.	*Journal Paper*: Balanced Mix Design for High RAP Asphalt Mixtures Prepared with Recycling Agents
IL	Mar. 2021	Case study, BMD implementation.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures: Illinois Department of Transportation (IDOT)
	Jan. 2017 to Aug. 2019	I-FIT, long-term aging, flexibility index, aging rate, benchmarking different aging protocols, LPLC & PPLC.	*Project*: Development of Long-Term Aging Protocol for Implementation of the Illinois Flexibility Index Test (I-FIT)
	2018 to 2021	Softener-type modifiers, bio-based modifiers, long-term field aging, asphalt rheology, asphalt chemistry, I-FIT, HWTT, Glover-Rowe parameters, viscoelastic transition temperature, black angle, FTIR, GPC.	*Project*: Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements
	2020 to 2023	Relatively soft aggregate, surface stability and durability.	*Ongoing Project*: Optimizing the Use of Local Aggregates in Stone-Matrix Asphalt (SMA)
ME		Case study, BMD implementation.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures: Maine Department of Transportation (MaineDOT)
		Performance tests, HWTT, IDEAL-CT, SSR, baseline rutting and cracking performance, polymer-modified asphalt binders.	*Journal Paper*: Balanced Mix Design Benchmarking of Field-Produced Asphalt Mixtures in Maine, U.S.
MD	Oct. 2019 to Dec. 2021	Performance testing mix criteria, IDEAL-CT, IDT test, optimum binder content, potential surrogate test correlation, volumetric property baseline.	*Project*: Evaluating Maryland Asphalt Mixtures Using Balanced Mix Design for Durable Pavements
	2023	Define distress criteria, cracking and rutting, IDEAL-CT, HT-IDT, repeatability, test variability, Ultrasonic Pulse Velocity (non-destructive QA method), volumetric benchmarks.	*Dissertation:* Incorporating Performance Requirements in Asphalt Mixture Design
MN	Jun. 2018	Pavement cracking, rutting, cracking criterion, rutting criterion, Illinois Flexibility Index, IDEAL-CT, HWTT, different application conditions.	*Project*: Balanced Design of Asphalt Mixtures

	Aug. 2024	Cold-recycling processes, recycling additives, rejuvenating asphalt emulsions, mixture stability at 40 °C, IDEAL CT.	*Project*: Cold Asphalt Recycling Technologies Using Rejuvenating Asphalt Emulsion—Impact, Implementation, Specification
	Jun. 2019	Disc-shaped compact tension (DCT) fracture energy test, threshold values.	*Project*: Disc-Shaped Compact Tension (DCT) Specifications Development for Asphalt Pavement
	Jan. 2021	Cracking tests and criteria, DEAL-CT, DCT, QC/QA, reheating effect.	*Project*: Test Methods to Quantify Cracking Resistance of Asphalt Binders and Mixtures
	Nov. 2023	Loose mix aging procedures, cracking resistance, preliminary field validation, loose mix aging, effects of silo storage, mix, hauling, mix reheating, specimen storage, and asphalt weathering, lab-to-field aging correlation.	*Project*: Validation of Loose Mix Aging Procedures for Cracking Resistance Evaluation in Balanced Mix Design
	Mar. 2023	Polymer asphalt, cracking resistance, IDEAL-CT, I-FIT, sensitivity, cyclic and monotonic loading tests, binder content, rheological properties.	*Project*: Impact of Polymer Modification on IDEAL-CT and I-FIT for Cracking Resistance Evaluation of Asphalt Mixtures
	Apr. 2025	Recycling agents, higher RAP content (30% and 40%), field test, laboratory aging levels, field core testing, performance monitoring.	*Project*: Long-Term Testing and Analysis on Asphalt Mix RA Field Sections
MO	May 2023 to Dec. 2024	Recycled polymers (GTR, waste plastic), virgin polymers (SBS, PPA), dense grade mixture, SMA, CT-Index, plant and lab mix, correlating field observations to laboratory results.	*Project*: Implementation of Balanced Mixture Design in Missouri Test Sections with Modifiers
	Aug. 2024	SMA, stone-on-stone contact, volumetric properties, gradation adjustments, IDEAL-CT, HWTT.	*Project*: Development of Preliminary Balanced Mix Design Method for Stone Matrix Asphalt
	May 2017 to Jun. 2020	Detailed climatic study, property-temperature relationships, DCT, HWTT, plant-produced mixtures and field core, IDEAL-CT, I-FIT, field performance data, specification thresholds for the cracking and rutting tests.	*Project*: Support for Balanced Asphalt Mixture Design Specification Development in Missouri
	May 2022	A coherent BMD/QC/QA framework, variability of performance tests, aging conditions (from plant to laydown and field cores).	*Project*: Development of Holistic Methodologies for Improving Asphalt Mix Durability (Yr 1)
	Jul. 2022	Dense grade mixture, appropriate thresholds of mixture performance tests, RAP, DC(T), I-FIT, IDEAL-CT, HWTT, softer grade binder, rejuvenator, GTR.	*Journal Paper*: Application of Balanced Mix Design Strategies to Missouri Dense-Graded Asphalt Mixtures

	May 2024	SMA, high-level HMA, alternative local aggregate, accelerating friction testing, HWTT, IDEAL-CT, both volumetric and performance thresholds, structural performance simulation, cost-effective analysis.	*Project*: Analysis of Asphalt Mixtures Using Alternative Aggregate in SMA and Superpave
NE	Sept. 2020	Performance test methods, performance criteria, semicircular bend test method, gyratory stability, performance space diagram.	*Project*: Feasibility and Implementation of Balanced Mix Design in Nebraska
	May 2023 and May 2025	Performance-based methodologies, preliminary BMD framework, HWTT, I-FIT, TSR, IDEAL-RT, HT-IDT, G-stability, IDEAL-CT, long-term aging conditioning, lab-compacted and field core specimens, field data.	*Project*: Nebraska Balanced Mix Design—Phase I & Phase II
	Jul. 2024 to May 2026	Iowa, Minnesota, and Missouri require a thermal cracking test, low temperature cracking resistance, SCB test, DCT test, IDT Creep Compliance and Strength Test, Thermal Stress Restrained Specimen Test (TSRST), I-FIT, BBR test.	*Ongoing Project*: Evaluation of Low-Temperature Cracking (LTC) Performance Testing Methods to Assess Nebraska Asphalt Mixtures
	May 2019 and Jul. 2024	Short-term aging, Response Surface Methodology (RSM), RTFO, Dynamic Shear Rheometer (DSR); Kinematic Viscosity (KV); Bending Beam Rheometer (BBR); Fourier-Transform Infrared (FT-IR) Spectroscopy; elemental analysis; Saturate-Aromatic-Resin-Asphaltene (SARA) analysis.	*Project*: Asphalt Binder Laboratory Short-Term Aging, Phase I & Phase II
	May 2024 and Nov. 2024	High RAP, recycling agents, triglycerides and fatty acids (TF), antioxidants, zinc diethyldithiocarbamate (ZnDEC), moisture damage resistance, short- and long-term aging condition, high-temperature rutting, mid- and low-temperature cracking assessments.	*Project*: Effect of Antioxidant Additives and Recycling Agents on Performance of Asphalt Binders and Mixtures—Phase I & Phase II
NV	Dec. 2021	Intersections, gradation specification, long-term cracking and stripping, resistance rutting criterion.	*Thesis*: Balanced Mix Design of Asphalt Mixtures for Intersections
	Aug. 2024	BMD framework for flexible airfield, rutting test criteria, test protocols, APA, High Temperature Indirect Tensile highway test, field performance, PMLC, IDEAL-RT, HWTT.	*Dissertation*: Advancing FAA Asphalt Mix Design—Evaluation of Rutting Mechanical Tests for Balanced Mix Design

	Mar. 2022	Virtual site visits and interviews of seven DOTs, BMD and performance tests implementation efforts, QA, organizational structure, staffing level, workspace, annual asphalt tonnage, industry experiences and practices.	*Project*: Positive Practices, Lessons Learned, and Challenges When Implementing Balanced Design of Asphalt Mixtures—Site Visits
NH	Jun. 2019	Different laboratory conditioning protocols, complex modulus (E*), S-VECD, SCB, DCT fracture tests on mix, DSR test on binder.	*Project*: Incorporating Impact of Aging on Cracking Performance of Mixtures During Design
NJ	Mar. 2021	Case study, BMD implementation.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures—New Jersey Department of Transportation (NJDOT)
	Jul. 2012 to Sept. 2015	Dense-graded asphalt mixtures, High Performance Thin Overlay (HPTO), performance-based asphalt mixture design, performance criteria, dense mix, SMA, OGFC, overlay tester, two test device benchmark.	*Project*: Performance Testing for HMA Quality Assurance
NM	Apr. 2018 to Apr. 2019	Rutting criteria, cracking criteria, HWTD, SCB, DCT, OT.	*Project*: Development of a Balanced Asphalt Mixture Design Procedure for New Mexico
	Feb. 2025	Initial BMD method, 15% RAP, rutting and cracking performance criteria, HWTT, SCB.	*Conference Paper:* Initial Approach to Develop Balanced Mix Design Method in New Mexico
NJ	Mar. 2021	Rutting and fatigue cracking methods and criteria, HT-IDT, IDEAL-CT.	*Project*: Performance Evaluation of Asphalt Mixtures Statewide
	Nov. 2022	Rutting and fatigue cracking methods and criteria, APA, HWT, HT-IDT, SCB, IDEAL-CT.	*Journal Paper:* Statewide Assessment of Balanced Mixture Design for New York State's Asphalt Mixtures
NC	Aug. 2021 to Dec. 2024	Performance metrics (cracking and rutting), construction projects, index-volumetrics relationships, performance volumetrics relationships, STA protocols (2 hr STA better agreement between LMLC and PMLC), QA/QC, current tolerance limits for binder content and in-place density on performance, S_{app} and RSI.	*Project*: Performance Evaluation of HWY-2017-29 Project Asphalt Mixtures and Pavement
	Aug. 2022 to Jul. 2024	BMD framework, identify appropriate performance-related testing protocol for incorporation into mix design and QA/QC; initial threshold limits; a draft BMD procedure, integrating performance tests into QA/QC operations.	*Project*: Balanced Asphalt Mix Design for North Carolina

ND	2022	Balanced Mix Design Gyrations, rutting, low-temperature cracking, fatigue cracking resistances, Analysis of Variance (ANOVA).	*Project*: Developing Balanced Mix Design Gyrations (N_{design}) for North Dakota's HMA Pavements
OH	Jan. 2024 to Jul. 2028	Rutting, QA, rutting test protocols, operating parameters, failure criteria.	*Project*: Re-evaluating Asphalt Rutting Test for Balanced Mix Design and Quality Assurance Acceptance
OK	Jul. 2018 to Aug. 2019	Determining BMD test procedures, specifications and special provisions, I-FIT, IDEAL CT.	*Project*: Implement Balanced Asphalt Mix Design in Oklahoma
	2018 to 2021	HWTT, I-FIT, IDEAL-CT, mixture: (1). 9.5 mm NMAS, PG 76-28 modified binder and 15% RAP, (2) 12.5 mm NMAS mix with PG 70-28 modified binder and 12% RAP, (3). 19 mm NMAS base course contains PG 64-28 modified binder with 30% RAP and a rejuvenator.	*Test Track Study:* Phase VII (2018-2021) NCAT Test Track Findings
	Jun. 2024	Field performance of BMD mixes, 3D laser imaging technology, percentage cracking, IRI, rut depth, mean profile depth.	*Conference Paper:* Enhancing Pavement Performance through Balanced Mix Design—A Comprehensive Field Study in Oklahoma
	Jun. 2024	Determining BMD test procedures, specifications and special provisions, I-FIT, CT Index.	*Conference Paper:* Pioneering the Evaluation of Balanced Asphalt Mix Design in Oklahoma
OR	Nov. 2020	A new long-term aging protocol, performance-based specifications.	*Project*: Development of a Balanced Mix Design Method in Oregon
	Aug. 2021	Performance tests, threshold values, FN, HWTT, SCB.	*Conference Paper:* Development of a Balanced Mix Design Method in Oregon to Improve Long-Term Pavement Performance
PA	Jun. 2021 to Jul. 2023	Fatigue Testing Protocol, HWTD, 35% RAP.	*Project:* Development of a Fatigue Testing Protocol for Supporting Integrated Design of Asphalt Pavement
TN	Sept. 2023 to Dec. 2025	Benchmarking of approved dense-graded asphalt mixtures, performance-based asphalt mixture design, recommendations for performance criteria, IDEAL CT, TN CT, IDEAL RT, HWTT, HT-IDT.	*Project*: Benchmarking Study of TDOT D Mixtures for Balanced Mix Design
TX	Mar. 2021	Case study, BMD implementation.	*Project*: Case Studies on the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures—Texas Department of Transportation (TxDOT)

	2018 to 2021	Test track study*,* BMD vs. the Superpave volumetric approach, HWTT, overlay tests, mixtures: 9.5 NMAS mixes with the same PG 70-22 modified binder and 20% RAP binder replacement but different gradations and volumetric properties, the BMD mix: 5.5% total binder content, Superpave: 4.7% total binder content.	*Test Track Study:* Phase VII (2018-2021) NCAT Test Track Study
	Sept. 2011 to Aug. 2012	RAP/RAS mix design, performance evaluation system, project-specific service conditions, Overlay Test (OT), HWTT, dynamic modulus (not a good indicator for cracking resistance), soft and modified binder.	*Project*: Balanced RAP/RAS Mix Design and Performance Evaluation System for Project-Specific Service Conditions
	Aug. 2022	Different BMD approaches, experimental evaluation, overlay tester, HWTT, gradation adjustment.	*Project*: Develop Guidelines and Design Program for Hot-Mix Asphalts Containing RAP, RAS, and Other Additives through a Balanced Mix-Design Process
	Oct. 2024 to Aug. 2027	Defensible and practical skid resistance laboratory assessment, long-term skid resistance, mix type, gradation, fines quality.	*Project*: Incorporating Lab Skid Measurements into the Balanced Mix Design Process
	Mar. 2024	Cracking and rutting distresses, Automated Testing System with Zero Intervention (AMAZE) with robotic arm; IDEAL CT, IDEAL-RT, IDT strength test.	*Project*: Asphalt Mixture Automated Testing System with Zero Intervention (AMAZE)
	Sept. 2024 to Aug. 2027	Durable RAP mixes, minimum virgin binder content, overlay test, IDEAL-CT, statistically sound laboratory experimental design, correlation between field performance and laboratory mix cracking properties.	*Project*: Evaluating Minimum Virgin Binder Contents for Durable Recycled Asphalt Pavement (RAP) Mixes
	Sept. 2021 to Apr. 2025	Lab-molded density, balancing high lab-molded density values at plant production, field performance, QC/QA, acceptable range of lab-molded densities for laboratory mix design.	*Project*: Establish Performance-Based Acceptable Lab-Molded Density Range for Mix Design and QC/QA.
UT	Nov. 2015 to Dec. 2017	Specification test, BBR (low temperature), I-FIT (intermediate temperature), test sensitivity, aging effect.	*Project*: Balanced Asphalt Concrete Mix Performance, Phase II—Analysis of BBR and SCB Tests
	May 2017 to Mar. 2019	Performance tests, BBR (low temperature), I-FIT (intermediate temperature), different loading rates.	*Project:* Balanced Asphalt Concrete Mix Performance in Utah, Phase III—Evaluation of Field Materials Using BBR and SCB-IFIT Tests

	Nov. 2018 to Sep. 2020	Cracking performance tests, IDEAL-CT, I-FIT, test repeatability and precision, tolerable threshold specification value.	*Project:* Balanced Asphalt Concrete MIX Performance in Utah, Phase IV—Cracking Indices for Asphalt Mixtures
	Dec. 2019 to Jul. 2021	Field evaluation, BBR, IFIT, IDEAL-CT, performance thresholds, aging effects, RAP, (BBR for low temperature and IDEAL-CT for intermediate temperature are chosen).	*Project:* Balanced Asphalt Concrete Mix Performance in Utah. Phase V: Field Evaluation for Intermediate and Low-Temperature Cracking
	Oct. 2019	Field performance, laboratory performance evaluation, flexibility index.	*UTC Project:* Prevention of Low Temperature Cracking of Asphalt Pavements Using the Bending Beam Rheometer
	Jul. 2022	IDEAL-CT, repeatability, within-lab and between-lab variability.	*Project*: Balanced Asphalt Concrete Mix Performance in Utah, Phase VI—Multi-Laboratory Testing of Ideal-CT
	Jul. 2022	Field samples, flexibility index, field aging, flexibility index, variability, BBR, flexibility index, between-lab variability.	*UTC Projects:* Field Performance of Asphalt Mixtures Based on Flexibility Index Results Testing of Field Cores to Determine Performance of Asphalt Mixtures Field Performance of Asphalt Pavements at Low and Intermediate Temperatures
	Feb. 2023	IDEAL-CT, repeatability, within-lab and between-lab variability.	*UTC Project*: Variability of the IDEAL-CT Test for Pavement Cracking to Achieve a Balanced Asphalt Mix Design
WA	Dec. 2020	Reclaimed asphalt material, LMLC, FMLC, FMFC, short- and long-term aging of binders and mixtures, rheological and cracking tests, ΔTc, CT-Index, HWTT, test criteria, short- and long-term standard specification revisions.	*Project:* RAP Reset—Responsibly Optimizing Recycled Materials Use in AC and Pavement Performance Life
WI	Nov. 2016 to Sept. 2018	Air voids regression, mixture performance tests, I FIT for intermediate temperature cracking resistance, DCT for low-temperature cracking resistance, HWTT for rutting and moisture resistance, withdrawing the regressed air voids design requirement.	*Project:* Regressing Air Voids for Balanced HMA Mix Design
	Jun. 2019 to Mar. 2021	A preliminary BMD specification, benchmarking existing WisDOT mix designs, HWTT, IDEAL-CT, DCT, database of mixture performance test results, MT, HT, and SMA.	*Project:* Balanced Mixture Design Implementation Support

	May 2024	BMD tests and criteria for QA/QC, validation of BMD tests and criteria, test sections, FWD, lab-to-field correlations, lab-to-lab comparisons, IDEAL-CT, HWTT, production variability, key variability statistics, preliminary BMD specification criteria.	*Project:* Balanced Mixture Design Pilot and Field Sections
Federal	Jun. 2024	Multi-state deployment of three technologies, first topic is "Development of Balanced Mix Design (BMD) for asphalt." Provides shared funding & implementation guidance for DOTs still at the planning stage.	*FHWA:* Demonstration to Advance New Pavement Tech. Pooled Fund – TPF 5 478 (Start 2024)
	Jan. 2025 to Mar. 2028	Aging, BMD, quality assurance, mix aging protocols, create practical aging procedures and correction factors so plant-produced mixes can be judged quickly in QA programs.	*NCHRP Project 09-70:* Guidelines for Incorporating Aging Effects on Balanced Mix Design for Quality Assurance
	Apr. 2025 to Jun. 2028	End-to-end framework (design → plant → lay down), mapping tests to applications and climates, framework, production, placement, performance tests.	*NCHRP Project 09-71:* Framework for Design, Production, and Placement of Balanced Asphalt Mixtures
	Mar. 2025 to May 2027	Quantify how mix or test method variations shift BMD results; guidance for spec limits, sensitivity, BMD tests, mix variables, implementation.	*NCHRP Project 09-72:* Sensitivity Evaluation of Balanced Mix Design Performance Tests.
	Sept. 2014 to Apr. 2016	Designed coordinated field experiments to link lab cracking tests with pavement performance, cracking resistance, field experiments, candidate tests.	*NCHRP Project 09-57:* Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures.
	Jun. 2018 to Oct. 2022	Assessed precision/bias of 10 cracking tests and set ruggedness limits before large-scale validation, ruggedness, variability, asphalt cracking tests.	*NCHRP Project 09-57A:* Ruggedness of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures.
	Apr. 2024 to Oct. 2026	Places selected tests on in-service roads to confirm predictive accuracy and finalize criteria, field validation, cracking, laboratory tests.	*NCHRP Project 09-57B:* Field Validation of Laboratory Cracking Tests of Asphalt Mixtures.
	May 2013 to Mar. 2021	Developed loose mix oven procedure and climate-based model to simulate up to 20 yr aging, long-term aging, simulation, oven aging, climate model.	*NCHRP Project 9-54:* Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction

	Mar. 2020 to Oct. 2022	Step-by-step DOT/industry guide for migrating QA and pay factors from volumetrics to performance, implementation guide, performance specs, BMD, and QA.	*NCHRP Project 10-107:* Guide for Implementing Balanced Mix Design Specifications
	Published Oct. 2023	How to plan and monitor open road or test track sections to correlate BMD tests with rutting/cracking, field validation, guidelines, test sections, NCAT.	*CAPRI-23.001-R:* Guidelines and Recommendations for Field Validation of Test Criteria for Balanced Mixture Design (BMD) Implementation,
	May 2017 to Sept. 2018	Produced draft AASHTO spec and practice giving agencies menu of tests/thresholds for BMD adoption, framework, AASHTO, performance tests, BMD.	*NCHRP Project 20-07/Task 406:* Development of a Framework for Balanced Mix Design
	Jan. 1987 to Jun. 1990	First performance-related mix design system covering fatigue, rutting, moisture and aging, AAMAS, performance criteria, mixture analysis.	*NCHRP Project 09-06(01):* Asphalt-Aggregate Mixture Analysis System (AAMAS)
	Jun. 2012 to Aug. 2015	Defined 2 hr/135 °C (design) and 4 hr/135 °C (performance) protocols to mimic plant aging, short-term aging, conditioning, AASHTO R 30 update.	*NCHRP Project 9-52:* Short-Term Laboratory Conditioning of Asphalt Mixtures
	Aug. 2009 to Dec. 2015	Quantified variability among LMLC, PMLC & PMFC specimens; drafted QA/verification practice, volumetrics, mechanical properties, variability, QA.	*NCHRP Project 9-48:* Field Versus Laboratory Volumetrics and Mechanical Properties, conducted by Louisiana Transportation Research Center research team and completed in 2015.

A3: First Round Survey on Current Implementation of Balanced Mix Design (BMD) in State Agencies

Introduction

This survey is a key component of the synthesis study titled:
"*Balanced Mix Design—A 1-Year Reality Check on Quality Control Testing and State DOT Adoption*"
led by Dr. Baoshan Huang and Dr. Kai Huang at the University of Tennessee, Knoxville (UTK) and sponsored by the Louisiana Transportation Research Center (LTRC).

This survey aims to assess the current status, challenges, and opportunities associated with the implementation of Balanced Mix Design (BMD) across state agencies in 2025.

Only questions with a red asterisk * are required. All other questions are optional, and you may skip them if you prefer not to answer. Each section includes multiple-choice and open-ended questions. Your contact information will be kept confidential, and your answers will be used solely for research purposes.

Section 1: General Information

1. Name of the Agency/Department: ___________________________
2. State: ___________________________
3. Name: ___________________________
4. Contact Information of Respondent: ___________________________
5. What is your position in your organization? ___________________________
6. Would you be open to a brief phone or Zoom interview if we have any follow-up questions?

   ☐ Yes

   ☐ No

   ☐ Other: ________________________________

Section 2: Research efforts and related research projects (completed or ongoing)

1. Has your agency conducted, or are you currently conducting, any shade, pilot, or research projects related to Balanced Mix Design (BMD)?

   ☐ Yes

   ☐ No

   ☐ Other: ______________________________

   If YES, please indicate which of the following topics are addressed in the studies by checking the appropriate boxes below:

   ☐ Mix categories (please specify in the box below)

   ____

   ☐ Performance-related tests (please specify in the box below)

   ____

   ☐ BMD test criteria (preliminary recommendations or final specifications)

   ☐ Volumetric properties in BMD design and acceptance

   ☐ Field trials

   ☐ High RAP/RAS contents

   ☐ Benchmarking studies

   ☐ Aging effects (if specify long-term or short-term aging in the box below)

   ____

   ☐ Correlation of performance test and field performance

   ☐ Performance tests and criteria for QA/QC.

   ☐ Variability between LMLC, PMLC & PMFC

   ☐ Potential surrogate test correlation

   ____

☐ Other (please specify in the box below)

____

Please specify the duration of the checked studies from start to completion or planned completion:

____

____

2. What specific <u>research topics</u> does your agency prioritize for further research related to BMD?

____

____

Comments for Section 2: Research efforts and related research projects (completed or ongoing). (if any):

____

____

Section 3: Available data resource for your state DOT

1. Please specify the <u>available data resource</u> for your state DOT for performance tests validation, performance criteria and specifications.

☐ Research projects

☐ Shadow projects

☐ Pilot projects

☐ Test tracks

☐ Pavement Management System

☐ Utilizing ME design software

☐ Other: ______________________________

Comments:

Section 4: BMD Framework

1. What is the scope of BMD implementation in your state? (Examples: specific mix category, interstates, pilot projects, all projects, etc.)?

   ____

   ____

2. Which BMD approach(es) does your agency use for BMD implementation? (check all that apply)

   ☐ Approach A: Volumetric design with performance verification.

   ☐ Approach B: Volumetric design with performance optimization.

   ☐ Approach C: Performance-modified volumetric design.

   ☐ Approach D: Performance-based design.

   ☐ Still evaluating and TBD

   ☐ Other: ____________

3. Would you please elaborate on the rationale for choosing specific approach(es)? (if any)

   ____

   ____

4. What PERFORMANCE TESTS are included (or plan to include) in your BMD process (mix design performance evaluation and the production QC/QA? (select all that apply)

   Cracking resistance: (check all that apply)

   ☐ IDEAL-CT

   ☐ SCB (AASHTO TP105)

   ☐ SCB-Jc

☐ Indirect Tensile (IDT) Strength

☐ I-FIT

☐ Disk-shaped Compact Tension (DCT)

☐ Overlay Test (OT)

☐ Flexural Beam Fatigue

☐ S-VECD test

☐ Other: ___________ (including state modified test protocol mentioned above)

Comments: ____

Rutting resistance: (check all that apply)

☐ APA

☐ Hamburg Wheel Tracking Test (HWTT)

☐ IDEAL-RT

☐ HT-IDT

☐ Flow number test

☐ Hveem Stability

☐ RLT

☐ Marshall stability test

☐ Other: ___________ (including state modified test protocol mentioned above)

Comments: ____

Moisture damage resistance: (check all that apply)

☐ IMC

☐ TSR

☐ HWTT

☐ Cantaboro

☐ Modified Lottman test

☐ Other: ___________ (including state modified tests)

Comments:

____

Do you plan to consider **friction performance** in your BMD implementation

☐ Yes (if yes, what friction test will you consider?) (please specify in the box below)

____

☐ No

☐ Other: ____________________________

5. Do you use the **SAME** set of laboratory tests for both the performance evaluation during design and the production QC/QA testing?

☐ Yes

☐ No

Please elaborate on the rationale of choosing the same or different set of laboratory tests:

____

____

6. Have any thresholds and acceptance criteria been established for these performance tests?

☐ Yes

☐ No

If YES, please provide the preliminary or final criteria/specifications, including any variations based on traffic levels, mix types, additives, or other relevant categories.

Are there differences in performance-related tests and criteria between the **mix design phase** and **production phase**?

☐ Yes

☐ No

If yes, what is the difference and why ______________________________
(optional)

Criteria and thresholds of performance tests for **design**, please specify for Cracking, Rutting, and Moisture damage, respectively:

____

____

Criteria and thresholds of performance tests for **Acceptance and QA**, please specify for Cracking, Rutting, and Moisture damage, respectively:

____

____

Comments for Question 6:

____

____

7. What are the sampling locations and testing frequency in BMD QA/QC acceptance? (please specify mix type, sampling position, and testing frequency)?

____

____

8. Which mixture aging protocols does your agency follow for BMD testing?

Cracking Resistance Tests (specify duration, temperature, and protocol):

____

____

Rutting Resistance Tests (specify duration, temperature, and protocol):

____

____

Moisture Susceptibility Resistance Tests (specify duration, temperature, and protocol):

____

____

9. Considering the feasibility regarding the time of conditioning and performance tests, do you utilize **SAME** aging protocol on performance tests for mix design, verification, acceptance, and QA/QC?

   ☐ Yes

   ☐ No

   ☐ Other: ______________________________

   If NO, please provide the aging protocols for mix design, verification, acceptance, and quality assurance respectively.

   ____

10. Are there any specified lag time or dwell time requirements prior to conducting performance testing in your state?

    ☐ Yes
    ☐ No
    ☐ Other: ______________________________

    If yes, what are those lag and dwell time requirements? ___________

11. Did you find any impact of lag time or dwell time on your test results in your experience? (on test results or work schedule)

    ____

    ____

    Comments on Section 4 BMD framework:

    ____

    ____

Section 5: Relationship with Volumetric Design

1. Please list any potential adjustments or relaxations to volumetric requirements that may be considered during the implementation of BMD approaches:

☐ Aggregate limit (using any unapproved materials before BMD)
☐ Gradation limit range
☐ Air voids
☐ Binder grade and sources
☐ Binder content
☐ Voids in Mineral Aggregate (VMA)
☐ Voids Filled with Asphalt (VFA)
☐ Ndesign
☐ Other volumetric parameters (please specify in the box below):
____
☐ RAP content limit
☐ Using additives with new technologies
☐ Other _________________

Comments: _____________________________

2. Have you experienced, or do you anticipate, any adjustments to mix design compaction efforts, such as changes to N_{design} values or compaction methods?

____

____

3. Could you please provide examples of any adjustments or relaxations to volumetric requirements in your state's specifications? (if any)

____

____

Comments on Section 5 Relationship with Volumetric Design:

____

____

Section 6: Gaps and Issues

1. What are the primary challenges your agency encounters in implementing Balanced Mix Design (BMD)? (select all that apply)

☐ Need of standardized and validated test methods

☐ Need of standardized and validated conditioning methods

☐ Need of performance test criteria and specifications

☐ Insufficient validation of performance tests

☐ Variability in test results

☐ Equipment or resource limitations

☐ Lack of training/staffing

☐ Resistance to change from volumetric-based approach

☐ Other: ___________

2. Have you observed any unintended consequences or issues after implementing BMD?

____

____

3. Could you share the most commonly heard feedback or concerns from contractors regarding BMD implementation? (such as Equipment Investment, Increased Testing Costs and Time, etc.)

____

4. Any general concerns or comments on BMD implementation?

____

____

A4: Second Round Survey on Current Implementation of Balanced Mix Design (BMD) in State Agencies

Introduction

This *second round survey* is designed to gather more in-depth information from state transportation agencies on their ongoing and planned practices within the framework of **Balanced Mix Design (BMD)**. Building on the results of the first round survey conducted earlier in 2025.

Responses will help identify common challenges, gaps, and regional trends to support the development of a consistent and efficient QA/QC framework for BMD implementation across SASHTO member states and beyond.

Section 1. General Information

1. Name of the Agency/Department and State: ____________________
2. Name: ____________________
3. Contact Information of Respondent: ____________________
4. Current Role and Responsibilities: ____________________

Section 2. Current (Planned) QA/QC Testing Practices

Q1. **What QA/QC tests/verifications are used for asphalt mixtures in your flexible pavements?**
Please specify both constituent/volumetric verification and performance tests.

- Constituent and Volumetric verifications currently used:

  ____

  ____

- Performance tests & aging protocols currently used (e.g., IDEAL-CT, HWTT, SCB, TSR, etc.):

  ____

  ____

- Performance tests & aging protocols planned for use:

  ____

  ____

Q2. **Are the same performance tests currently used or planned for use in both *mix design* and *QA/QC*?**

(Many state DOTs mentioned their concerns on QA performance testing, including 1) time for testing results, 2) production variability, 3) no established thresholds, 4) surrogate testing under evaluation, 5) too early to determine)

☐ Yes ☐ No ☐ Partially

Please explain the rationale (e.g., turnaround time, variability, or equipment availability):

____

____

Q3. **Do contractors need to perform the same set of volumetric verification and performance tests in their QC?**

☐ Yes ☐ No ☐ Partially

If “No” or “Partially,” please provide essential examples:

____

Q4. We received feedback that short-term aging (STA) is often used for design, but long-term aging (LTA) is crucial for cracking tests, however, needs longer turnaround time. **Could you please share your thoughts on how to balance the importance of LTA and the extended testing time it entails?**

____

____

Section 3. Performance Criteria and Thresholds

Q5. **If preliminary thresholds for performance tests for DESIGN were established, how were they determined? If not, how do you plan to set the thresholds based on what types of test results?** (as the high variability in test results)
(e.g., statistical significance & distribution, field correlation, research project, national guidance, etc.)

____

____

Q6. **Are threshold values set or adjusted for PLANT-PRODUCED mixtures during QA/QC (e.g., considering reheating or long-term aging effects)? Under the same aging conditioning as in MIX DESIGN?**

☐ Yes ☐ No ☐ Not yet determined

Please describe current status or future plans:

____

____

Section 4. Variability, Precision, and Tolerances

High variability in performance testing was among the most frequently cited concerns in the first-round survey.

Q7. **How does your agency account for single-lab and cross-lab variability in performance testing?**

- Are inter-lab studies or round-robins conducted? ☐ Yes ☐ No
- What tolerance ranges or reproducibility metrics (e.g., COV, D_2S, bias limits) are used?

____

____

Q8. **For high-variability tests (e.g., IDEAL-CT, HWTT), what specific actions are taken to manage variability?**
(e.g., replicate testing, reheating control, operator training, specimen handling)

____

____

Section 5. Pay Factors, Schedule, and Specification Integration

Q9. **Has your agency integrated BMD-related performance test results into *pay-factor* or *acceptance* frameworks? If not, any ideas or comments?**

____

____

Q10. **Do you expect extended testing time for performance-based QA/QC to influence construction schedules?**

☐ Yes ☐ No ☐ Uncertain

If yes, what solutions might mitigate delays (e.g., rapid tests, more resource, prequalification)?

____

____

Section 6. Future Research and Support Needs

Q11. **What additional research, data, guidance, or ideas would most help your agency advance BMD QA/QC?**
(e.g., rapid test precision, equipment certification, regional calibration, field correlation studies)

____

____

Q12. **Has your agency participated (or be interested in) in regional/multi-state BMD studies?**

☐ Yes ☐ No ☐ Maybe

Please provide more details:

____

____

Section 7. Tiers of BMD (New AASHTO Standard)

Tier 1 – Baseline Requirements for BMD specifications

- Meets selected constituent, volumetric, and mechanical test requirements for performance characteristics.
- Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.

Tier 2 – Increased Flexibility

- Allows relaxation of certain constituent and volumetric requirements to provide more freedom in material selection and mix adjustments.
- Emphasizes mechanical testing while reducing reliance on specific constituent and volumetric parameters.

- Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.

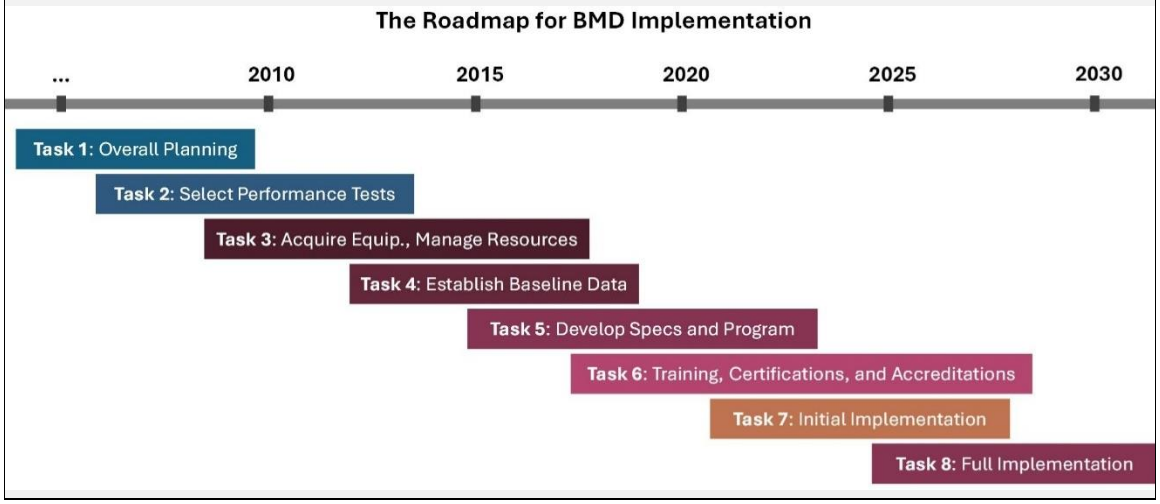
Tier 3 – Performance-Driven Design

- Minimizes detailed constituent and volumetric requirements, with primary reliance on performance-based material & design optimization, and mechanical testing to validate mixture performance.
- Certain constituents and volumetric properties may be designated as **report-only** for informational and quality assurance (QA) purposes.

Q13. The concept of BMD tiers is relatively new, reflecting different levels of specification flexibility. **What is your agency's current status regarding TIER classification? What are your general thoughts on this tiered approach, and how might it be integrated into your QA program and contractor QC practices?**

Section 8: General BMD Implementation Strategy: A Roadmap (modified based on the Eight Potential Tasks by FHWA)

Please check the appropriate boxes to indicate whether your state has implemented or plans to implement the following tasks. Additionally, please provide the corresponding timeline up to the date of this survey or your anticipated timeline. The objective of this section is to outline a roadmap for BMD implementation in your state, as conceptually illustrated below:



Notes: Here is **a checked box** ☒ you may use. If a box is checked, please select one of the *THREE* statuses: **Completed / In Progress / Planned** are noted as **C/IP/PL** in each subtask.

Task 1: **Overall Planning**

☐ Initial consideration of implementing BMD approaches (initially referred to as performance-based design). *(C/IP/PL)*

☐ Identifying Issues and Resources and the need for performance-based approaches, especially when incorporating new or reclaimed pavement materials. *(C/IP/PL)*

☐ Formation of a stakeholder panel focused on BMD implementation (e.g., including DOT staff, industry partners, researchers, etc.). *(C/IP/PL)*

Timeframe for Task 1 implementation (actual or planned):

____

____

Task 2: **Identify typical pavement distress and corresponding performance tests**

☐ Consider utilizing mechanical tests that have already been developed in your state. *(C/IP/PL)*

☐ Identifying and assessing the appropriateness of new performance tests **(for mix design),** considering the feasibility of time and equipment requirements. *(C/IP/PL)*

☐ Identifying and assessing the appropriateness of new performance tests **(for quality assurance),** considering the feasibility of time and equipment requirements. *(C/IP/PL)*

☐ Validating the performance tests through feasibility, repeatability, production, and between-lab variability. *(C/IP/PL)*

Timeframe for Task 2 implementation (actual or planned):

____

____

Task 3: **Acquiring, managing available resources, initial training, and inter-laboratory variability studies of performance testing equipment**

☐ Acquire equipment, manage available resources, initial training. *(C/IP/PL)*

☐ Conduct Inter-Laboratory Studies. *(C/IP/PL)*

Timeframe for Task 3 implementation (actual or planned):

____

____

Task 4: **Identify and establish a database of BMD**

☐ Review historical data & information/performance management system *(C/IP/PL)*

☐ Conduct benchmarking studies based on the asphalt mixtures from the State's mix categories. *(C/IP/PL)*

☐ Conduct Shadow project(s) and analyze production data. *(C/IP/PL)*

☐ Determine any adjustment or loosen requirements based on the data: (1) aggregate (natural sand usage), (2) volumetric parameters, (3) recycled materials usage, (3) other additives. *(C/IP/PL)*

Timeframe for Step 4 implementation (actual or planned):

____

____

Task 5: **Specifications and Program Development**

☐ Develop sampling and testing protocols for incorporating performance tests into Quality Assurance (QA) programs. *(C/IP/PL)*

☐ Explore surrogate tests for acceptance with correlation to the asphalt mix design performance test. *(C/IP/PL)*

☐ Develop related specifications & policies for use in upcoming pilot projects. *(C/IP/PL)*

☐ Conduct pilot projects. *(C/IP/PL)*

☐ Preliminarily modify necessary specifications. *(C/IP/PL)*

Timeframe for Task 5 implementation (actual or planned):

____

____

Task 6: **Training, Certifications, and Accreditations**

☐ Development/update BMD-related training and certification program. *(C/IP/PL)*

☐ Establish and implement a statewide proficiency testing program. *(C/IP/PL)*

Timeframe for Task 6 implementation (actual or planned):

____

____

Task 7: **Initial Implementation**

☐ Technology transfer: communicate the changes and new requirements to both industry and agency personnel. *(C/IP/PL)*

☐ Identify the scope for project selection. *(C/IP/PL)*

Timeframe for Task 7 implementation (actual or planned):

____

____

Task 8: **Full Implementation**

☐ Your DOT agency has fully implemented BMD approach(s) to all or certain state mix categories. *(C/IP/PL)*

If yes, please specify the mix categories that have been implemented using BMD approach(s): ____

Timeframe for Task 8 implementation (actual or planned):

____

____

Comments on **Section 8** (if any):

____

End of Survey

Thank you very much for your time and contribution!