BMD
IMPLEMENTATION WORKING GROUP

BEYOND VOLUMETRIC PROPERTIES:

BRINGING BALANCED MIX DESIGN INTO ASPHALT QUALITY ASSURANCE

INTRODUCTION

For decades, asphalt mixture quality assurance has relied heavily on volumetric properties such as asphalt content, air voids, voids in mineral aggregate, and in-place density. Asphalt binder content and aggregate gradation were historically central to this approach because they were practical, repeatable, and directly tied to plant control. Air voids, voids in mineral aggregate (VMA), voids filled with asphalt, and in-place density later provided additional information about how those materials were proportioned, compacted, and arranged within the mixture. These measures remain valuable because they are familiar, comparatively efficient to obtain, and closely tied to long-standing production and acceptance practices due to their reflection of mixture consistency. Balanced mix design (BMD) changes the discussion by directly evaluating mixture behavior through mechanical tests that indicate resistance to key pavement distresses.



Historically, asphalt content and gradation were used as the primary tools for managing mixture quality because they described the basic proportions of binder and aggregate being produced. However, experience showed that controlling only the proportions of binder and aggregate did not fully explain how a mixture behaved after production. Volumetric properties added an important layer of information by evaluating how those materials packed together in the compacted mixture, including the effects of aggregate structure, absorbed asphalt binder, effective binder volume, dust content, and air voids. This was an important advancement because it helped explain differences between laboratory-designed and plant-produced mixtures that were not apparent from asphalt content and gradation alone (FHWA Demonstration Project No. 74 and the subsequent NCAT Report 95-04 by Kandhal, Foo, and D'Angelo).

LEARN MORE ABOUT THE HISTORY OF MIX DESIGN AND THE MOVEMENT TO BMD

SCAN ME

BMD represents the next step in that progression. Just as volumetric properties expanded quality assurance beyond asphalt content and gradation, BMD expands beyond mixture proportions and volumetric structure by directly evaluating mechanical response.

BMD can identify meaningful changes in mixture behavior that may not be reflected by volumetric properties that only capture proportions of the major components of the mixture. At the same time increased test sensitivity to factors that frequently vary in production creates additional challenges when BMD is applied from mix design into quality assurance. A test that is useful for mix design may not necessarily be well-suited for routine production decisions. Once a result is tied to corrective action or payment; delay, laboratory throughput, specimen handling, fabrication variability, and changing plant conditions become substantially more important.

This distinction is especially important because the use of BMD changes as a mixture moves through the major phases of implementation: mix design, mix design verification, and production. During mix design, BMD is used to establish whether a laboratory-designed mixture meets the mix design requirements. During mix design verification, it helps determine whether the approved design can be reasonably reproduced under project-specific or plant-produced conditions. During production, quality assurance must do more than confirm that the approved laboratory-designed mixture met design criteria. It must answer two practical questions: does the produced mixture closely mimic the mixture design that was initially approved, and does the produced mixture still meet the intended level of performance? Those questions must be answered within the time, staffing, and variability constraints of field projects. As a result, agencies and contractors considering BMD for quality assurance should expect not just new tests, but a different operating environment. Accordingly, this document examines how the use of BMD in asphalt mixture quality assurance changes the relative importance of material control, production conditions, sample handling, testing logistics, and measurement variability compared with traditional volumetric practice.

QUALITY ASSURANCE (QA) CONTEXT

Quality assurance provides the program framework for determining whether the materials and constructed product meet the specified requirements. In FHWA's quality assurance framework, this includes the sampling, testing, inspection, acceptance, quality control, personnel qualification, laboratory qualification, independent assurance, dispute resolution, and verification practices used to provide confidence in project materials and construction quality. FHWA identifies State highway agency quality assurance programs as part of the stewardship process for Federal-aid projects, with requirements established under 23 CFR 637 Subpart B. Recent FHWA QA resources, including the Documenting FHWA Quality Assurance Assessment 2022: Summary Report and the Quality Assurance Stewardship Review Summary Report 2019–2023, provide useful context for how these QA program elements are evaluated and where implementation challenges commonly arise.

Mix design verification and production quality assurance serve related but different purposes. During mix design, the goal is to establish a proposed combination of component materials in selected proportions (including asphalt binder, aggregate, recycled asphalt materials, and additives) that meet the mix design specification criteria. There are usually sufficient time and resources available to condition mixtures carefully, conduct tests, evaluate anomalies,

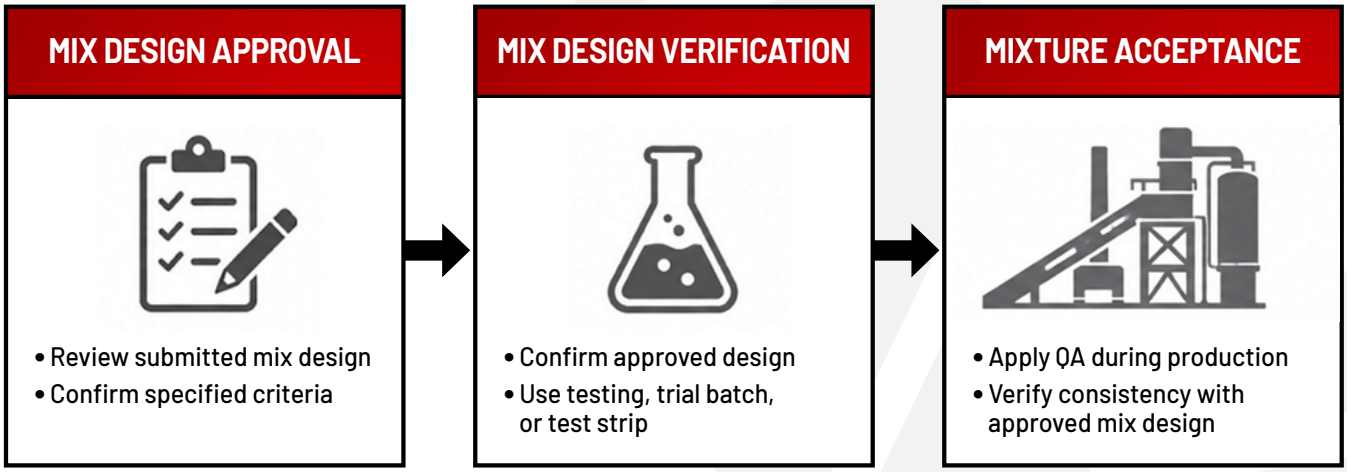


Figure 1. Applications of BMD Mix Design Specifications

and make adjustments before the mixture is submitted for approval. Testing can be planned around laboratory convenience rather than around the pace of an asphalt plant or paving operation. In contrast, production quality assurance, whether as contractor quality control or agency acceptance, operates under a different set of constraints. The mixture is being produced continuously, raw materials may change over time, and plant conditions may change during production. Contractor quality control and agency acceptance decisions must often be made with limited turnaround time for laboratory results and finite resources. BMD tests generally take longer, require more resources and care with specimen fabrication, and are more sensitive to materials, production, and testing factors' variability than traditional volumetric properties. Agencies must rethink how acceptance will work in practice rather than assuming the existing framework can simply absorb a new set of mechanical tests. Contractors need to reexamine how to perform effective quality control that can inform ongoing production in a timely fashion.

Variability is a key reason the two stages behave differently. Some variability is inherent to materials, including binder source differences, reclaimed asphalt materials, aggregate properties, and stockpile fluctuations. Additional variability arises during production and placement through temperature, moisture, sampling, handling, and storage. Many of those factors affect both volumetric properties and BMD performance properties, but their impact is amplified when acceptance depends on mechanical tests that are more sensitive to binder quality, effective binder content, thermal history, and specimen fabrication.

WHAT IS DIFFERENT

BMD test results are more sensitive to several factors that may not meaningfully affect volumetric results. This does not mean volumetric properties are unimportant; rather, it means the critical control points change. A mixture can satisfy familiar volumetric ranges and still exhibit unacceptable cracking or rutting resistance based on a selected threshold. Conversely a mixture could be outside typical volumetric ranges and have acceptable performance characteristics. Fundamental differences in quality assurance between BMD and volumetric properties can be broken down into three types of factors: 1) materials, 2) production, and 3) testing.

MATERIALS FACTORS

Materials represent one of the clearest areas where the distinction between volumetric acceptance and BMD-based quality assurance becomes important. While conventional volumetric properties may confirm that mixture proportions remain within the established limits, BMD results can highlight changes in binder (quantity and quality), recycled materials, aggregate characteristics, and gradation that can alter mixture performance in ways those volumetric checks do not fully capture. These material-related factors may influence both mix design and production, but their quality assurance significance increases during production because agencies and contractors must make timely decisions under conditions of continuous operation.

Asphalt binder source and grade

Volumetric properties are largely blind to binder property differences. Two binders that meet the same performance grade can still differ in chemistry, aging susceptibility, relaxation behavior, and interaction with aggregate or recycled binder. Those differences may have little effect on volumetric properties but can produce meaningful shifts in BMD results (particularly cracking resistance). That matters in quality assurance because a mixture may appear unchanged from a traditional volumetric perspective while its cracking resistance moves in a different direction. When agencies use BMD for acceptance, binder source verification, certification, and change-management procedures become more important than they may have been in a volumetric-only framework.



Recycled asphalt materials
Volumetric properties are also relatively blind to recycled binder contribution. Asphalt content and gradation may indicate whether recycled asphalt materials are being introduced at the expected rate, but they do not fully capture how much reclaimed binder is available to act as a binding agent or how stiff that binder is within the final mixture. That distinction becomes critical when BMD tests are part of quality assurance. In practice, two mixtures with similar asphalt content and gradation can behave differently if the recycled binder contribution changes because of recycled asphalt variability, blending differences, or stockpile management. Where recycled materials are used, contractors may need tighter control over source consistency, fractionation, prequalification, or allowable variability than a volumetric specification alone would suggest.

Aggregate properties, G_{sb}, and effective binder
Aggregate properties also play a role. Volumetric properties rely on accurate aggregate bulk specific gravity (G_{sb}) because key measures such as voids in mineral aggregate (VMA) and effective asphalt content (V_{be}) are calculated using the aggregate specific gravity. In a BMD framework, the issue becomes broader than the correctness of a calculation. Cracking resistance results can be highly sensitive to the effective binder available in the mixture, which may shift if asphalt absorption or aggregate proportions change. A change that appears minor on a volumetric worksheet may cause a meaningful change in effective binder and therefore in performance.

Aggregate gradation control
Aggregate gradation remains important under both systems, but the reason is different. In volumetric practice, gradation is often adjusted to keep the mixture within air void or VMA targets. Under BMD, staying inside an existing gradation band may still be insufficient if the shift changes internal aggregate structure, binder demand, cracking resistance, or rutting susceptibility.

This is one reason agencies should be careful not to assume that compliance with conventional gradation limits will automatically ensure BMD compliance. Gradation control remains necessary from the consistency perspective, but it may need to be paired with other controls that better preserve the approved performance balance.

For production quality assurance, this means that compliance with an existing gradation band should not automatically be assumed to preserve the approved BMD response, particularly when gradation movement changes aggregate structure or effective binder demand.

PRODUCTION FACTORS

Production conditions can affect any asphalt mixture, but they matter more visibly for BMD tests. Volumetric properties are relatively insensitive to modest shifts in production temperature, silo storage, or mixture reheating history, particularly when those shifts do not significantly change asphalt content or measured gradation. BMD results, especially cracking resistance, can be strongly influenced by these variations.

Plant discharge temperature, moisture management, silo storage duration, haul time, and sample cooling and reheating can all alter binder aging and the condition of the mixture that ultimately is evaluated in the mechanical test. That sensitivity creates an important quality assurance question: is the test capturing the behavior of the produced mixture, or is it capturing the combined effect of production plus sample handling? The answer has direct implications for where samples are taken, whether plant and roadway samples are expected to match, and how quickly specimens must be prepared.

The production environment can amplify the effects of BMD test results and be manifested as variability. A plant can move through changes in burner settings, stockpile moisture contents, baghouse fines return, and silo storage times over the course of a production run. In a volumetric system, those fluctuations may not be critical to specification tolerances. In a BMD system, the same fluctuations may affect performance measurements and trigger a need for corrective action.

TESTING FACTORS

The largest practical differences between volumetric properties and BMD often arise not from the concept of mechanical testing itself, but from the way those tests fit into routine quality assurance. Turnaround time for laboratory results, test frequency, conditioning/aging protocols, and laboratory repeatability all become central implementation issues.

Testing timing
Traditional volumetric checks are generally compatible with routine production decision cycles because they can be completed with relatively modest specimen fabrication and established laboratory workflows. Many existing programs rely upon asphalt content, gradation, and volumetric testing that can be completed the same day or within 24 hours for quality control or acceptance.

BMD testing usually requires representative theoretical maximum specific gravity values, additional specimen fabrication, and more time-intensive testing. These additional requirements do not make BMD unsuitable for quality assurance, but they highlight the importance that the testing program must consider available laboratory throughput and production feedback needs. Once a BMD test is tied to production decisions, agencies must decide how frequently samples can be tested, how quickly results are needed to support corrective action, and what happens when a result is not available until substantial tonnage has already been placed. Those questions are manageable, but they require explicit answers to balance risk between the agency and contractor. Without them, the quality assurance program risks becoming reactive, inconsistent, or overly dependent on judgment calls after the fact.

Conditioning/aging
Sample handling, reheating, and conditioning/aging are also more consequential under BMD. Many BMD tests are sensitive to how long a sample sits before compaction (lag time), how long a specimen sits after compaction (dwell time), how it is reheated, what conditioning/aging protocol is used, and whether contractor and agency laboratories apply the same process in practice. Differences that may not materially affect volumetric properties can meaningfully change a BMD result. This creates challenges for dispute resolution and for comparisons between contractor quality control and agency acceptance data. If two laboratories test nominally identical mixtures but use slightly different reheating or conditioning/aging practices, the disagreement may reflect protocol drift rather than a real change in production. Agencies therefore need tightly defined procedures, training, and verification plans before BMD results are used to support action thresholds or payment consequences.

Interlaboratory variability
Interlaboratory variability is another major consideration. Volumetric properties are not free from variability, but they benefit from decades of refinement and decision systems that are already calibrated to expected measurement scatter. Many BMD tests, particularly cracking resistance tests, exhibit higher variability (with coefficients of variation for within-laboratory repeatability exceeding 15 percent), and a meaningful share of that variability can be introduced during specimen fabrication rather than during testing. For quality assurance, that impacts how limits and tolerances should be set. Action thresholds must account for realistic production, sampling, and testing variability rather than relying on ideal single-laboratory precision. Agencies also need to guard against unintended overdesign, where mixtures are pushed to exceed a minimum threshold by a wide margin simply to account for variability in production and testing that could be more efficiently managed with other strategies. Finally, the program needs defensible decision rules that distinguish an actual production problem from normal measurement scatter.

WHAT STAYS THE SAME

Even when BMD is added to quality assurance, several fundamental principles will not change. First, the V_{be} of an asphalt mixture remains critical. Whether the agency is looking at volumetric properties or BMD results, the amount of binder effectively available in the mixture strongly influences behavior and is important in maintaining consistency. A BMD framework does not eliminate the need to understand asphalt content, absorption, and the impact of material changes on binder availability.

Second, proper sampling remains essential. Segregation, inconsistent sample location, poor splitting practices, and unrepresentative roadway sampling can undermine any quality assurance system. BMD may make those weaknesses more visible, but it does not create them; deficiencies in sampling compromise either framework.

Stratified random sampling and the use of defined lots and sublots also remain important. These practices help ensure that quality assurance results represent the material produced and placed over the full project, rather than isolated or convenient sampling points.

BMD may change what is measured, but it does not remove the need for a sound sampling plan, clear lot and sublot definitions, and unbiased procedures for selecting samples used for quality control, acceptance, verification, or dispute resolution.

Qualified personnel remain foundational to success. BMD testing places greater emphasis on training, procedural discipline, and technical judgment during specimen fabrication and testing. Competent laboratories are equally essential, as equipment verification, procedural consistency, and data quality management directly affect the defensibility of BMD-based quality assurance decisions. In some cases, these added demands may create the need for additional workforce and laboratory resources for agencies and contractors.

Many established quality assurance items remain important when BMD is incorporated, including technician qualification, laboratory qualification, equipment verification, test method consistency, data review, and clearly defined acceptance and dispute-resolution procedures.

PRACTICAL IMPLICATIONS

The transition from volumetric properties to BMD in quality assurance should be approached as a system change, not as a single test substitution. Agencies need to decide which performance risks they are trying to control during production, what degree of laboratory result delay is acceptable, how consistency of the asphalt mixture is best measured, and how much test variability can be tolerated within corrective-action and payment frameworks.

This document identifies the principal ways in which BMD changes the technical and operational demands of asphalt mixture quality assurance. **Table 1** organizes those considerations within the six core elements of quality assurance to show where agencies may need to revise procedures, decision rules, staffing expectations, and specification language when incorporating BMD into the different stages of asphalt mixture development within specifications. This information is intended as an implementation framework rather than a prescriptive model, recognizing that agencies may apply BMD at different levels of maturity and consequence.

In many cases, the most practical path is a phased approach. Agencies may begin by using BMD for mix design approval and verification, while retaining volumetric properties and in-place density as the primary production acceptance quality characteristics. As confidence grows, BMD testing can be introduced for informational testing or limited triggers before it is attached to stronger quality assurance consequences. At that stage, certain constituent- or volumetric-based acceptance requirements can be relaxed to amplify the impact of mechanical test results on BMD-focused quality assurance.

Regardless of the pace of implementation, successful programs will align specification language, sampling plans, laboratory procedures, dispute-resolution steps, and staffing expectations with the realities of production.

Balanced mix design offers agencies an opportunity to look beyond composition and proportions and toward performance-related mixture behavior. That opportunity is accompanied by operational challenges. BMD-based quality assurance is more sensitive than volumetric-based quality assurance to material variability, thermal history, conditioning/aging, and measurement variability; and it therefore requires greater discipline in sampling, logistics, laboratory practice, and decision-rule design. Production quality assurance is not simply mix design verification performed later in the process; it is a separate implementation challenge shaped by time pressure, throughput limits, and changing material conditions.

Table 1. Key Quality Control and Acceptance considerations for incorporating BMD across mix design approval, mix design verification, and production.

Item	Mix Design Approval	Mix Design Verification	Production
Quality Control			
Test turnaround time requirements (including internal dwell and lag limits)	●	●	●
Development of database	●	●	●
Trial production procedures while awaiting test results		●	●
Mix design adjustment allowances (internal contractor criteria)		●	●
Production corrective action procedures (internal contractor criteria)			●
Process for addressing acceptance program required actions			●
Contractor quality control failure ramifications (corrective action/shutdown)			●
Acceptance			
Data submission process, format, and storage capacity (raw values/averages and manufacturer-specific calculations/outputs)	●	●	●
Development of database	●	●	●
Mechanical test criteria (including specimen temperature and conditioning/aging time)	●	●	●
Mix design approval period	●	●	●
Sample size/mass requirements	●	●	●
Sample type (LMLC/PMLC)	●	●	●
Use of surrogate BMD test	●	●	●
Location of specimen fabrication	●	●	●
Test turnaround time expectations (including internal dwell and lag time limits)	●	●	●
Process to address test failures (confirmation, allowable adjustments, and required actions)	●	●	●
Volumetric criteria relaxation	●	●	●
Contractor quality control BMD test requirements	●	●	●
Contractor quality control data validation approach	●	●	●
Allowance for binder source changes	●	●	●
Specimen fabrication timing (same-day or next-day testing)		●	●
Sample location (plant/field)		●	●
Sample security and chain-of-custody procedures		●	●
Sample transportation procedures		●	●
Mix design verification approach (test strip, trial batch, etc.)		●	
Lot/sublot size for mechanical properties (frequency)			●
Lot/sublot size for volumetric properties (frequency)			●
Pay equation linking quality measure to pay			●
Quality measure (average, PWL, etc.)			●

Table 2. Key considerations (for the other core elements) for incorporating BMD across mix design approval, mix design verification, and production.

Item	Mix Design Approval	Mix Design Verification	Production
Qualified Personnel			
Technician certification/qualification	●	●	●
Qualified Laboratories			
Laboratory certification/qualification	●	●	●
Testing laboratory location (centralized/regional)	●	●	●
Mechanical test requirements by mix type	●	●	●
Additional equipment needs (ovens, water baths, saws, specimen conditioning/ aging equipment)	●	●	●
Equipment calibration requirements	●	●	●
Dispute Resolution			
Test result comparison limits (locally or nationally developed)		●	●
Test turnaround time expectations (including internal dwell and lag time limits)		●	●
Testing laboratory location (centralized/regional)		●	●
Independent Assurance			
Testing frequency			●
Mixture selection for evaluation			●
Test turnaround time expectations (including internal dwell and lag time limits)			●
Addressing issues from initial implementation through test standard/ specification maturity			●

REFERENCES

1. D'Angelo, J. A., Foo, K. Y., and Kandhal, P. S. (1995). *Field Management of Hot Mix Asphalt Volumetric Properties.* NCAT Report 95-04. National Center for Asphalt Technology, Auburn University, Auburn, AL.
2. Grogg, M., and Espinoza-Luque, A. (2023). *Documenting FHWA Quality Assurance Assessment 2022: Summary Report*. FHWA-HIF-23-021. Federal Highway Administration, Washington, DC.
3. Grogg, M. (2024). *Quality Assurance Stewardship Review Summary Report 2019–2023.* FHWA-HIF-24-074. Federal Highway Administration, Washington, DC.
4. Taylor, A. J. (2025). *Effect of Dwell Time and Lag Time on IDEAL-CT and IDEAL-RT Results – Expanded Study.* National Center for Asphalt Technology, Auburn University, Auburn, AL. Sponsored by the Consortium for Asphalt Pavement Research and Implementation (CAPRI). September 2025.