A Comprehensive BMD Protocol: Design Phase through Production Quality Assurance

NEAUPG

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Outline of Presentation

- BMD Definition
- Comprehensive BMD Definition
- BMD Approaches Description
- How Can a Comprehensive BMD be Achieved?
- Objective of this Study
- Question-by-Question Approach, Results, and Findings
- Developed Comprehensive BMD
- Conclusions

AASHTO & NAPA BMD Definition

"An asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate, and location within the pavement structure."

Definition of Comprehensive BMD

A balanced mixture design that remains balanced from the design phase through the production quality assurance (QA) phase.

Description of Four BMD Approaches

Approach A — **Volumetric Design with Performance Verification**

- The mixture must meet all volumetric requirements; otherwise, it must be redesigned.
- The mixture is then tested for performance.
- If it does not meet all passing criteria, then the mixture must be redesigned.

Approach B — **Volumetric Design with Performance Optimization**

- Similar to Approach A, it starts out with determining a preliminary OBC based on volumetrics. This mixture must meet all volumetric requirements.
- The mixture is then tested for performance at the preliminary OBC and at the OBC ±0.3% to ±0.6%.
- A final OBC is determined from these performance tests; however, the volumetrics only need to be met for the preliminary OBC.

Approach C — **Performance-Modified Volumetric Mix Design**

- This approach also starts with determining a preliminary OBC based on volumetrics, but it has flexibility which allows an agency to relax or eliminate some of the volumetric requirements based on the performance tests.

Approach D — **Performance Design**

- This approach establishes the mixture OBC based on performance tests with no requirements for volumetrics.

How Can a Comprehensive BMD be Achieved?

Even with available background resources, significant questions exist that are left for each agency to answer when developing a comprehensive BMD protocol.

1. Which BMD approach to use (A, B, C or D)?
2. Which pavement distresses should be included?
3. Which performance tests should be used to address the selected pavement distresses?
4. What mixture aging protocols should be used for performance testing both during mix design and during production QA?
5. Does a BMD remain balanced within the specified production tolerances and what if the source of asphalt binder changes but not the performance grade (PG)?
6. How can pass/fail criteria for the selected performance tests be developed?

Objective

- The objective of this study was to develop a comprehensive BMD protocol for an agency (MassDOT) utilizing one of the four approaches presented by both AASHTO and NAPA.
- The protocol would address each of the six previous questions just as any agency would have to do when developing a BMD protocol.

Question #1: Which BMD Approach to Use?

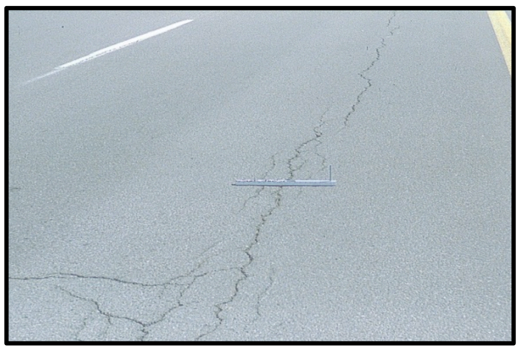
- Approaches B & C would require a separate study to determine new allowable volumetrics. Approach C would require a separate study to determine. Therefore, Approach C was eliminated.
- Since there was not enough data to verify the reliability of the performance tests for MassDOT mixtures, Approach D was eliminated.

Answer:

Approach A Volumetric Design with Performance Verification was selected by the Agency

Question #2: Which Pavement Distresses Should be Included?

- Based on a 2019 survey, the agency indicated that **bottom-up fatigue cracking at intermediate temperatures** was the predominant distress observed.
- MassDOT has been utilizing a rutting test (HWTT) to ensure that their VMA requirement of 1% above the AASHTO M 323 recommended minimum would not lead to mixture **rutting** and shoving in the field.



Answer:

Bottom-up Fatigue Cracking & Rutting

Question #3: Which Performance Tests Should be Used to Address the Selected Pavement Distresses?

Cracking

- Indirect Tensile Cracking Test (IDEAL-CT)
- The Illinois Flexibility Index Test
- Louisiana Semi-Circular Bending Test
- Texas Overlay Test
- Flexural Beam Fatigue
- Direct Tension Cyclic Fatigue Test using an Asphalt Mixture Performance Tester (AMPT)
- Indirect Tensile Test (IDT) Energy Ratio test developed by the University of Florida (UF)

Question #3: Which Performance Tests Should be Used to Address the Selected Pavement Distresses?

The following was prioritized when selecting a test:

1. The test should have an established standard specification, either AASHTO or ASTM
2. The test specimens can be prepared using the Superpave Gyratory Compactor (SGC)
3. Cost to perform the test
4. The test specimen preparation is simple and requires little to no cutting or gluing
5. Overall time to complete the test is low
6. The analysis of test data is not highly complex

Question #3: Which Performance Tests Should be Used to Address the Selected Pavement Distresses?

- Texas Overlay Test was eliminated because … → No AASHTO or ASTM standard
- Flexural beam fatigue test was eliminated… → Cannot use SGC to fabricate specimens
- Direct tension cyclic fatigue was eliminated… → High cost and longer time required for testing

The least expensive tests to implement were the ***IDEAL-CT test, Illinois Flexibility Index test, and Louisiana Semi-Circular Bending test***.

Question #3: Which Performance Tests Should be Used to Address the Selected Pavement Distresses?

- The IDEAL-CT test is the fastest test to conduct because no cutting and gluing is required.
- The IDEAL-CT test specimen size is identical to the specimen size utilized for the HWTT.

Answer:
IDEAL-CT & HWTT

Question #4: What Mixture Aging Protocols Should Be Used for Performance Testing Both During Mix Design and During Production QA?

- AASHTO R 30 recommendations for short-term aging (STA) were selected for **volumetric property determination** and for the **HWTT rutting performance test**.

Question #4: What Mixture Aging Protocols Should Be Used for Performance Testing Both During Mix Design and During Production QA?

- **NCHRP Project** suggested **for Massachusetts, LTA would be aging loose mixture for 3 days at 95°C to represent 12 years of field aging at a depth of 50 mm.**

- **Zhou et al.** conducted a study that used mixtures from Massachusetts and Texas to estimate an aging temperature using a time of 20 hours that would be equivalent to the 3 days at 95°C. **This study showed that aging loose asphalt mixtures at 110°C for 20 hours would be equivalent to NCHRP 3-day aging at 95°C**.

Question #4: What Mixture Aging Protocols Should Be Used for Performance Testing Both During Mix Design and During Production QA?

Answer:

- ***Short Term Aging (STA) for Mix Design and Rutting Evaluation***
  - *AASHTO R 30*
    - *For mix design a loose mixture is conditioned in a forced-draft oven for 2 hours at compaction temperature.*
    - *For the HWTT a loose mixture is conditioned in a forced-draft oven for 4 hours at 135°C and then brought to the compaction temperature.*
- ***Long-Term Aging (LTA) for Cracking Evaluation***
  - *Loose mixture STA performed, then 20 hours at 110℃, and then brought to compaction temperature.*

Question #5: Does a BMD Remain Balanced Within the Specified Production Tolerances and What if the Source of Asphalt Binder Changes but not the Performance Grade (PG)?

- A Previous study entitled was completed in 2019 investigated if a BMD could become unbalanced during production because of the OBC tolerance, aggregate gradation tolerances, and changes in the binder source.

Question #5: Does a BMD Remain Balanced Within the Specified Production Tolerances and What if the Source of Asphalt Binder Changes but not the Performance Grade (PG)?

- **Asphalt Binder Content**
  ±0.3% of the design optimum binder content (OBC)

- **Aggregate Gradation**
  Allowable deviation from Job Mix Formula varies by individual sieve size.

Tolerances from the MassDOT Quality Assurance Specification.

- **Asphalt Binder Source** (*Not Part of MassDOT QA Specifications)*
  Two different PG 64-28 asphalt binders from different sources were utilized.
  The binders had the same PG but significantly different relaxation properties as measured by Delta T_c (ΔT_c).

Binder Source	Continuous Grade	PG Grade	Delta T_c (ΔT_c)
A	66.2-28.4	PG64-28	+2.3°C
B	65.6-27.7	PG64-28 (Borderline)	-6.0°C

Question #5: Does a BMD Remain Balanced Within the Specified Production Tolerances and What if the Source of Asphalt Binder Changes but not the Performance Grade (PG)?

- BMD can become unbalanced during production due to production tolerances.
- IDEAL-CT showed that some mixtures produced at the lower limit of the OBC production tolerance were more susceptible to fatigue cracking.
- IDEAL-CT showed that the mixture fabricated with the binder source that passed ΔT_c provided a higher, or better, CT_{Index} than the mixture fabricated with the binder source which failed ΔT_c.
- The results indicated that production tolerances and binder sources should be taken into account when developing a comprehensive BMD protocol.

Question #5: Does a BMD Remain Balanced Within the Specified Production Tolerances and What if the Source of Asphalt Binder Changes but not the Performance Grade (PG)?

Answers:

- ***Evaluate a mixture's resistance to rutting at the upper production tolerance for OBC***
- ***Evaluate a mixture's resistance to cracking at:***
  - a. ***The lower production tolerance for OBC***
  - b. ***The lower production tolerance for OBC combined with the upper aggregate gradation production tolerances***
  - c. ***The lower production tolerance for OBC combined with the lower aggregate gradation production tolerances.***
- ***Include a parameter that can evaluate asphalt binder quality if the binder source changes during the production phase. The chosen binder parameter in this study was ΔT_c which should be checked during both the mixture design phase and the production QA phase.***

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

Distresses Included in the Comprehensive BMD

Distresses	Tests
Bottom-up fatigue cracking	IDEAL-CT
Rutting*	HWTT

** MassDOT has existing performance criteria for Rutting & Moisture Damage using the HWTT:*

- 12.5-mm maximum rut depth after 20,000 passes
- No stripping inflection point (SIP) before 15,000 passes
- Test temperature of 45°C
- These criteria were incorporated in the BMD protocol without modification.

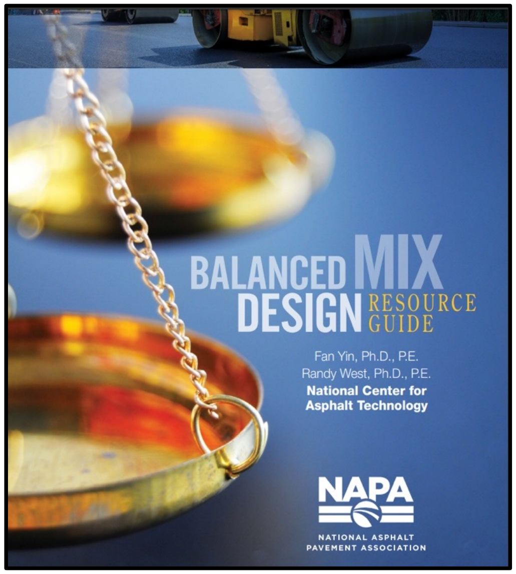
Thus, the focus was to develop a pass/fail criterion for bottom-up fatigue cracking using the IDEAL-CT.

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

Methodology

- NAPA's BMD resource guide presents steps that an agency can use when establishing criteria for performance tests under a BMD protocol:

    1. A statewide benchmarking experiment
    2. Agency conducts well-designed and well-constructed field experiments and also considers building one or more Long-Term Pavement Performance (LTPP) field experiments in their own state
    3. Perform shadow projects



Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

Methodology

- A benchmarking experiment was conducted to develop a preliminary criterion for the IDEAL-CT test.
- The experiment consisted of testing 21 plant-produced mixtures using the IDEAL-CT at 25°C. All were 12.5-mm Superpave dense-graded mixtures designed using a PG 64S-28.
- The results were analyzed statistically to determine the central tendency and variability of the results. These statistical analyses were then used to initially estimate a preliminary pass/fail criterion for the CT_{Index}.

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

Methodology

- The 21 benchmarking experiment mixtures had been placed between 2018 and 2022.
- These mixtures had also been placed prior to 2018, however, there was no guarantee that they would perform as they had historically because the sources of the asphalt binders had likely changed over the years.
- Instead of relying on potentially inaccurate performance data or solely on statistics, the resistance to bottom-up fatigue cracking of some of the benchmarking mixtures were predicted using the **AASHTOWare® Pavement Mechanistic-Empirical Design (PMED).**

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

Statistics	CT_{Index}
Mean	90
Median	86
50^{th} Percentile	86
60^{th} Percentile	94
70^{th} Percentile	103

- Based on these statistics, the agency could select one of these CT_{Index} values as a preliminary pass/fail criterion: 86, 94, or 103 at the 50^{th}, 60^{th}, and 70^{th} percentiles.
- However, the percentile to select would depend on what percentage of mixtures would exhibit fatigue cracking issues in the field. This was not known.
- It was decided to utilize a passing criterion of ≥ 90, where 43% of the data passed which meant that it was not highly biased in regard to having the mixtures either pass or fail. **AASHTOWare® PMED would then be utilized to validate this preliminary criterion.**

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

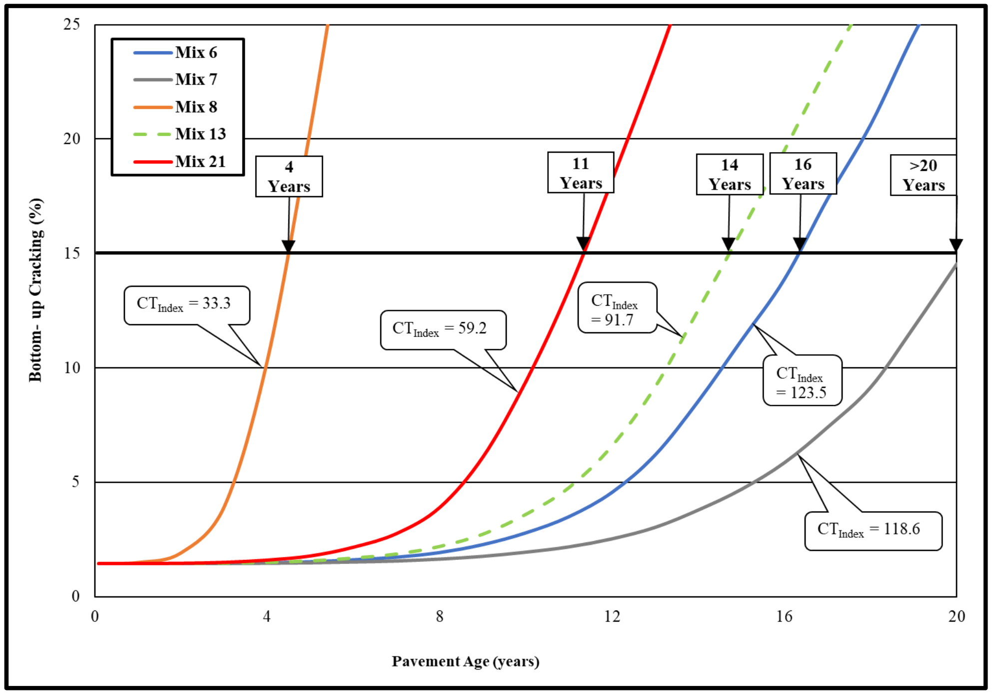
Validation of the Preliminary CT_{index} Criteria
Using AASHTOWare® PMED and Short-term Aging (STA)

- Five benchmarking experiment mixtures were selected with average CT_{Index} values of 123.5, 118.6, 91.7, 59.2, and 33.3.

- **For the preliminary CT_{Index} passing criterion of ≥ 90 to be valid, it was proposed that the fatigue cracking predictions from AASHTOWare® PMED should show that the 15% area cracked for the mixtures having a $CT_{Index} \geq 90$ would be reached after 12 years while those with a $CT_{Index} < 90$ would be reached in less than 12 years.**

Question #6: How Can Pass/Fail Criteria for the Selected Performance Tests be Determined?

IDEAL-CT Test Using Short-term Aging (STA)



- AASHTOWare® PMED predictions showed that the mixtures with a $CT_{Index} \geq 90$ will have more than 12 years of service before 15% of the area cracked. The mixtures with $CT_{Index} < 90$, had less than 12 years of service.
- Based on these findings, the preliminary passing criterion $CT_{Index} \geq 90$ is valid for dense-graded 12.5-mm STA mixtures used by the agency until long-term field data can be measured to further validate or invalidate its use.

Developed Comprehensive BMD Protocol

Mixture Design Phase

Determine Optimum Binder Content (OBC)	Check Asphalt Binder Quality	Performance Tests after STA	Evaluate Effects of Production Tolerances

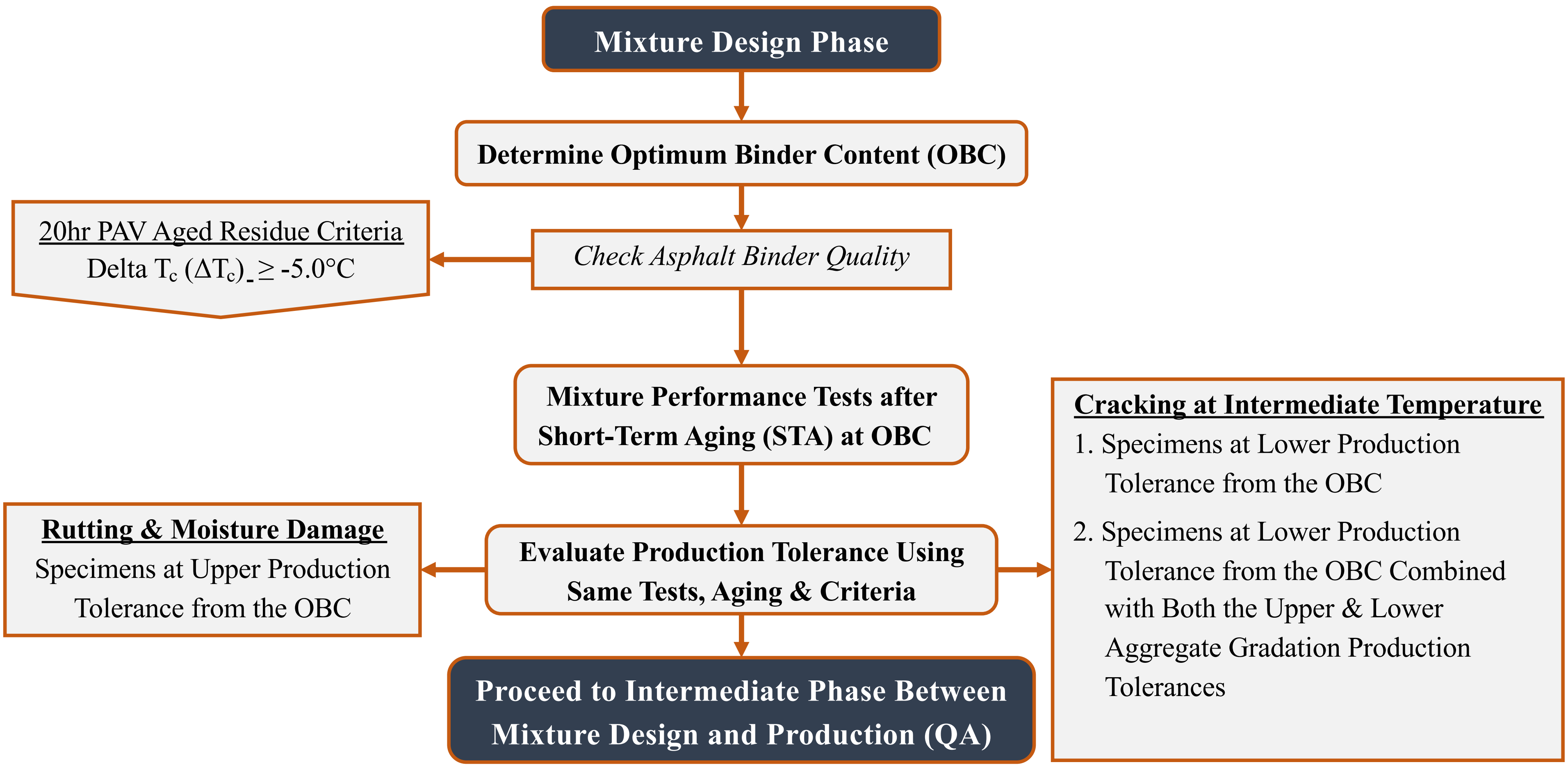
Intermediate Phase

Evaluate Cracking using IDEAL-CT at 25°C after LTA at OBC

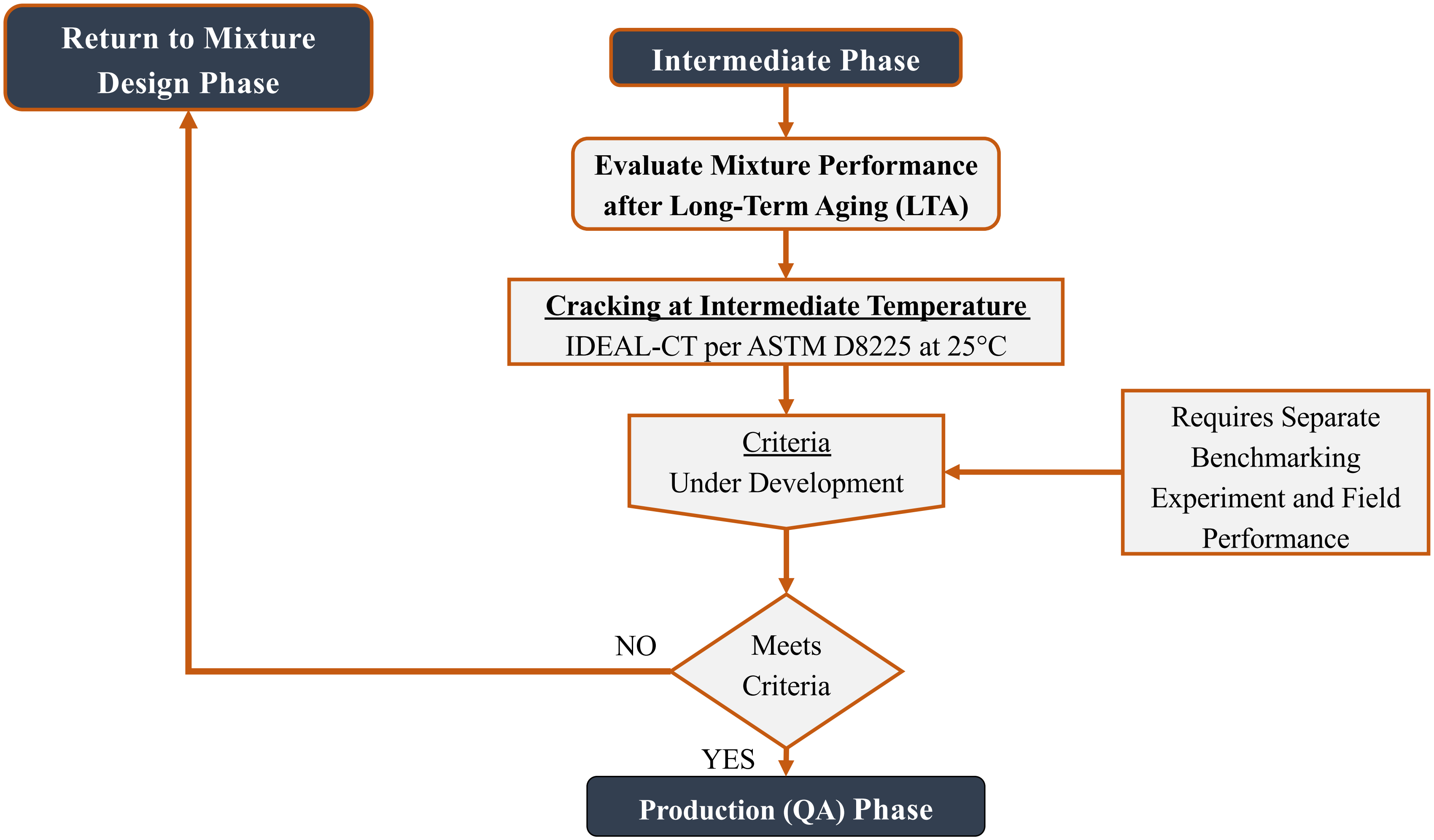
Production (QA) Phase

Performance Tests after STA	Check Asphalt Binder Quality

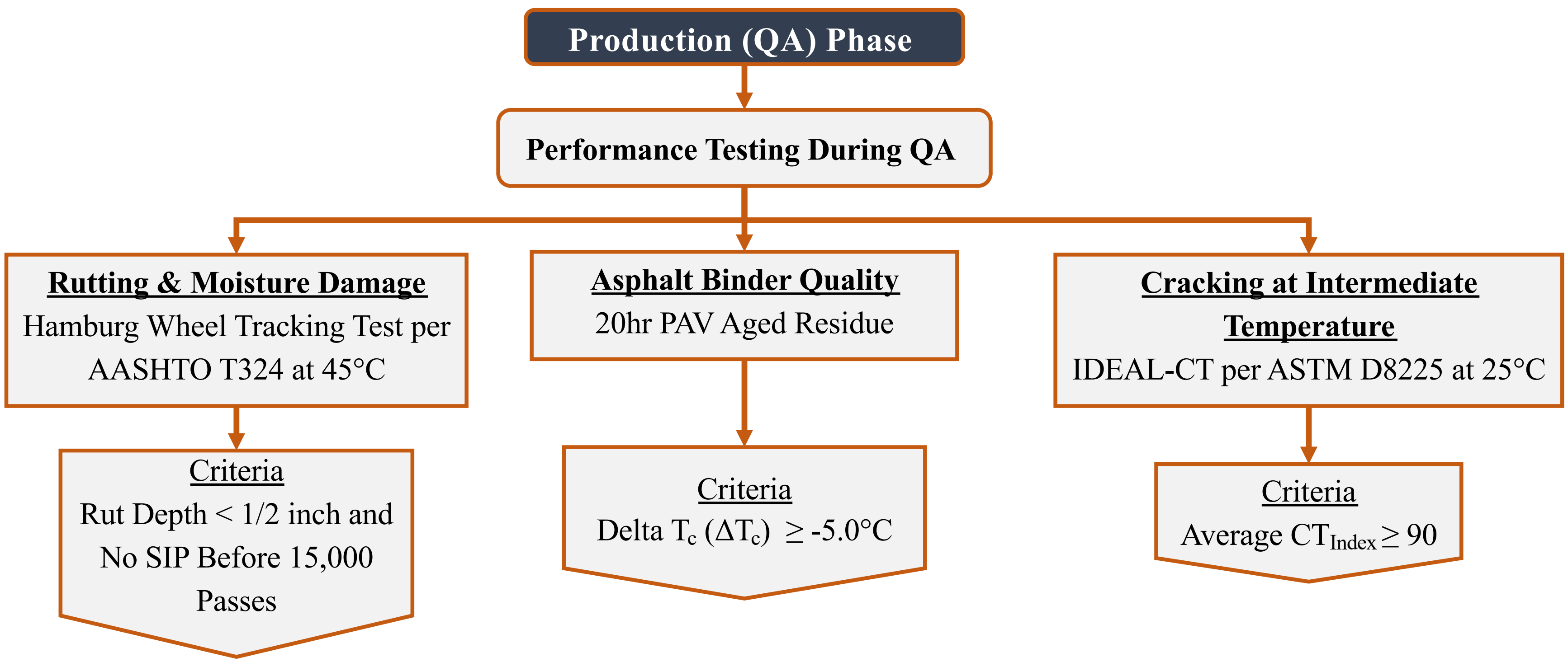
Developed Comprehensive BMD Protocol



Developed Comprehensive BMD Protocol



Developed Comprehensive BMD Protocol



Conclusions

- This study presented a methodology to determine and validate a performance criterion for the selected fatigue cracking test which was the IDEAL-CT.

  1. Using descriptive statistics, a preliminary test criterion was first obtained from benchmarking experiment data from testing of 21 plant-produced mixtures.

  2. The preliminary criterion was then validated using distress predictions from AASHTOWare® PMED. The results indicated that the preliminary criterion was valid.

- This methodology presents a valuable tool for agencies who have limited long-term field performance data.

Conclusions

- The passing criteria for the IDEAL-CT test was a $CT_{Index} \geq 90$ for 12.5-mm mixtures produced with a PG 64S-28 binder after STA. This criterion would be valid for both the mixture design and production QA phases.

- This criteria will likely be too stringent to use for mixtures subjected to LTA because the additional aging will decrease the performance test results. Thus, separate benchmarking experiments will be required.

Thank You