New England Transportation Consortium

# NETC 18-2: Framework of Asphalt Balanced Mix Design (BMD) for New England Transportation Agencies

## Technical Memorandum

### Task 2: Identify Candidate Performance Tests for Each Identified Common Distress.

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## I. Background

Building on the results from Task 1, the primary emphasis of Task 2 was to evaluate the pros and cons of different asphalt mixture performance tests and best match a performance test method to the state agency pavement distress(es) within a Balanced Mixture Design protocol. Although this sounds generally simple, there are multiple asphalt mixture performance tests and even multiple Balanced Mixture Design approaches.

## II. Identification of Candidate Performance Tests

A literature review was conducted to identify test procedures that match the needs of the NETC state agencies identified through the survey. The survey identified thermal cracking and fatigue cracking as the highest priority with rutting and moisture damage following. Therefore, a majority of the literature review focused on cracking tests. However, it is important to understand the need to include a rutting performance test as well in an effort to "balance" the performance of the asphalt mixtures. A performance specification too heavily dependent on one distress can allow asphalt suppliers to produce an asphalt mixture too soft (if the specification is only based on cracking) or too stiff (if the specification is only based on rutting).

The use of the NCHRP Project 9-57, *Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures*, test selection criteria was used to help narrow down the candidate test procedures. This consisted of the following seven (7) criteria:

1. Availability of test method
2. Simplicity
3. Variability
4. Sensitivity to mixture properties
5. Complexity of testing and analysis
6. Cost of equipment
7. Lab to field correlation

The NCHRP Project 9-57, with the help of a series of panel experts, identified a number of fatigue and thermal cracking tests which were found to best meet the seven criteria. Table 1 show those recommended tests. As indicated in Table 1, there are few instances where different test methods are recommended for different modes of cracking. For example, the Overlay Tester (OT) is recommended for both Reflection Cracking and Fatigue Cracking, while the SCB-LTRC procedure was recommended for Reflection Cracking, Fatigue Cracking and Top-Down Cracking.

**Table 1: Fatigue and Thermal Cracking Tests Identified Under NCHRP Project 9-57**

| Items | Reflection Cracking | Fatigue cracking | Thermal Cracking | Top-down Cracking |
|---|---|---|---|---|
| **Selected cracking tests** | 1. OT<br>2. SCB-LTRC<br>3. BBF | 1. Beam fatigue<br>2. SCB-LTRC<br>3. OT* | 1. DCT<br>2. SCB-IL<br>3. SCB-TP105 | 1. SCB-LTRC<br>2. IDT-Florida |
| **7 cracking tests** | 1. DCT<br>2. Three SCBs: SCB-TP105, SCB-LTRC, and SCB-IL<br>3. OT<br>4. Beam fatigue<br>5. IDT-Florida | | | |

The SCB Flexibility Index (SCB-IL) test procedure is recommended to be conducted at an intermediate temperature of 25ºC, and therefore, may not capture the low temperature cracking characteristics associated with thermal cracking. Therefore, it would not be recommended for thermal cracking.

## III. Candidate Performance Tests -Fatigue Cracking

Table 2 captures the general test method information regarding estimate costs and time required to conduct the test (specimen preparation, conditioning, and testing time). As the table indicates, the most expensive test procedure to implement would be the Flexural Beam Fatigue, primarily due to the necessity of purchasing a brick compactor for specimen preparation. The second most expensive fatigue cracking test would be the Direct Tension Cyclic Fatigue. The least expensive test procedures would be the SCB Flexibility Index, IDEAL-CT Index and SCB-LTRC. Regarding the time required for sample preparation and testing, the Direct Tension Cyclic Fatigue test is the most time consuming with the IDEAL-CT being the quickest to conduct (Figure 1). It should be noted that testing time can generally be decreased as the technicians gain additional experience. Conditioning times can also be reduced by utilizing a secondary environmental chamber for specimen conditioning, which can greatly increase the productivity of testing.

## Table 2: Candidate Fatigue Cracking Tests and Their General Information

| Test Method/Equipment | Costs | Testing Time | Total Time (after samples have been compacted) | | |
|---|---|---|---|---|---|
| | | | Cutting | Gluing | Conditioning |
| SCB Flexibility Index | < $20,000 (stand alone) | < 30 minutes for 3 specimens | Up to 6 hours for 4 specimens | N.A. | > 2 hours |
| Overlay Tester | $60,000 (Alone) $15,000 (AMPT) | 0.5 to 9 hours for 3 specimens | Up to 3 hours for 3 specimens | 4 to 24 hours | > 2 hours |
| Flexural Beam Fatigue | >$100k (includes compactor) | Hours to days (strain levels x replicates) | Up to 3 hours for 3 specimens | N.A. | > 2 hours |
| Direct Tension Cyclic Fatigue (AMPT) | >$70,000 | Up to 48 hours (DM E* + testing) | Up to 3 hours for 3 samples | 4 to 6 hours (overnight) | > 2 hours |
| IDT Energy Ratio (Florida DOT) | > $100,000 | Up to 24 hours for 3 specimens | Up to 1 hour for 3 specimens | 4 to 6 hours (overnight) | > 2 hours |
| IDEAL-CT Index | ≈ $15,000 $5,500 (SmartJig) | < 30 minutes for 3 specimens | N.A. | N.A. | > 2 hours |
| Louisiana SCB (Jc Parameter) | < $20,000 (stand alone) | Up to 8 hours for 9 specimens | Up to 8 hours for 9 specimens | N.A. | > 2 hours |

Assumptions:
1. Not including the costs of gyratory compactor and time associated with compacting specimens
2. Costs do not include;
   Wet saw = $6,000
   Core drill = $3,500
   Environmental Chamber = $5,000 to $10,000
3. Does not include time associated to bulk specimens after cutting/trimming
4. Large differences in curing time for epoxies used in gluing

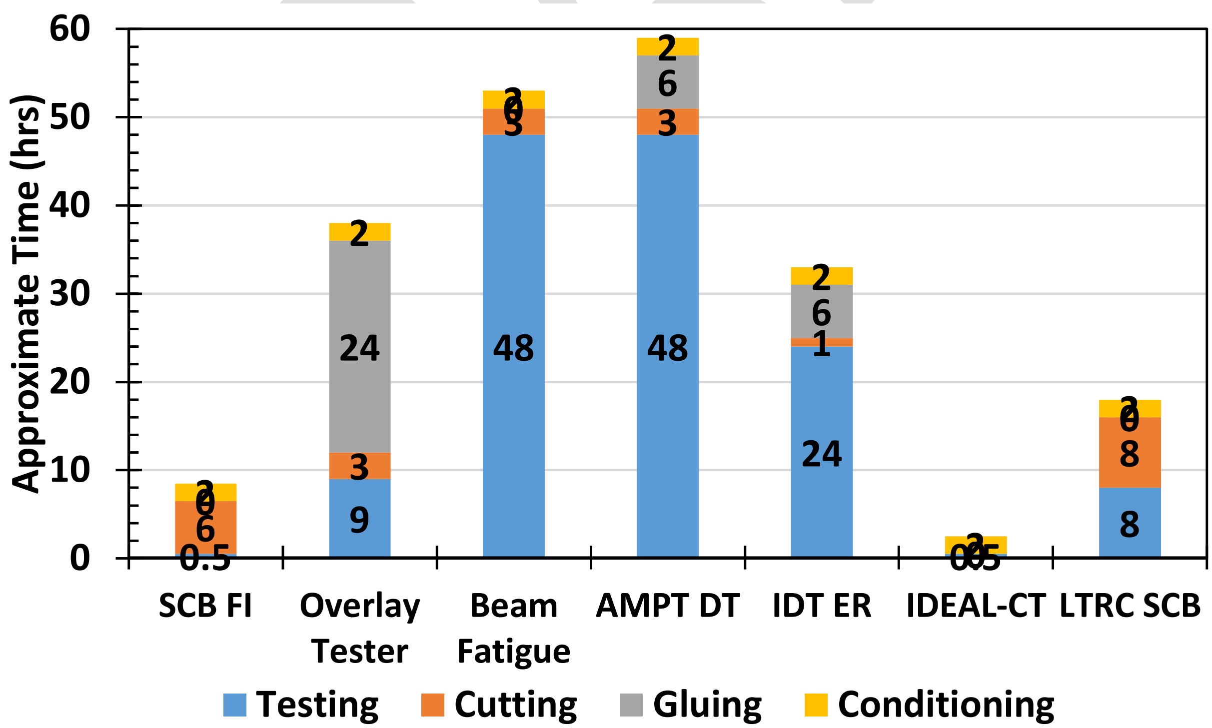


**Figure 1: Time Requirements to Various Fatigue Cracking Test Procedures**

## IV. Candidate Performance Tests -Thermal Cracking

Table 3 captures the thermal cracking test procedures and their general information regarding sample preparation, conditioning, testing time and costs. With respect to costs, the Thermal Stress Restrained Specimen Test (TSRST) was found to be the most expensive test to implement for thermal cracking evaluation. Either the Disk-Shaped Compact Tension (DCT) or the Indirect Tensile Test (IDT) Creep Compliance and Strength were found to be the least expensive test method to evaluate thermal cracking. However, the costs were not that significantly lower due to the need to cool the specimens to very low temperatures, as well as the test systems requiring more sensitive deformation, load cell, and thermal instrumentation.

Testing time (Figure 2) was found to be somewhat similar for some of the test procedures, mostly due to the requirements for conditioning. It was estimated that the IDT Creep Compliance and Strength test would be the quickest test procedure to conduct with the DCT test being the second quickest thermal cracking test to conduct. The Low Temperature SCB and TSRST tests were found to be the most time-consuming thermal cracking tests. It should be noted that testing time can generally be decreased as the technicians gain additional experience. Conditioning times can also be reduced by utilizing a secondary environmental chamber for specimen conditioning, which can greatly increase the productivity of testing.

**Table 3: Candidate Thermal Cracking Test Procedures and Their General Information**

| Test Method/Equipment | Costs | Testing Time | Total Time (after samples have been compacted) | | |
|---|---|---|---|---|---|
| | | | Cutting | Gluing | Conditioning |
| Disc-Shaped Compact Tension Test (DCT) | $75,000 (stand alone) | < 3 hours for 3 specimens | Up to 6 hours for 3 specimens | N.A. | 8 to 16 hrs (overnight) |
| Thermal Stress Restrained Specimen Test (TSRST) | $85,000 (stand alone) | 2 to 5 hours per specimen | Up to 3 hours for 3 specimens | Overnight | 5 to 6 hours @ 5C (overnight) |
| IDT Creep Compliance & IDT Strength | $75,000 (stand alone) | Up to 8 hours for 3 specimens | Up to 1 hour for 3 specimens | 4 to 6 hours (overnight) | > 3 hours @ test temperature |
| Low Temperature SCB (TP105) | Up to $100,000 | Up to 4 hours for 3 specimens | Up to 6 hours for 4 specimens | 4 to 6 hours (overnight) | 8 to 16 hrs (overnight) |
| SCB Flexibility Index | < $20,000 (stand alone) | < 30 minutes for 3 specimens | Up to 6 hours for 4 specimens | N.A. | > 2 hours |

Assumptions:

1. Not including the costs of gyratory compactor and time associated with compacting specimens
2. Costs do not include;
   Wet saw = $6,000
   Core drill = $3,500
   Environmental Chamber = $5,000 to $10,000
   Additional costs associated with liquid nitrogen
3. Does not include time associated to bulk specimens after cutting/trimming
4. Large differences in curing time for epoxies used in gluing

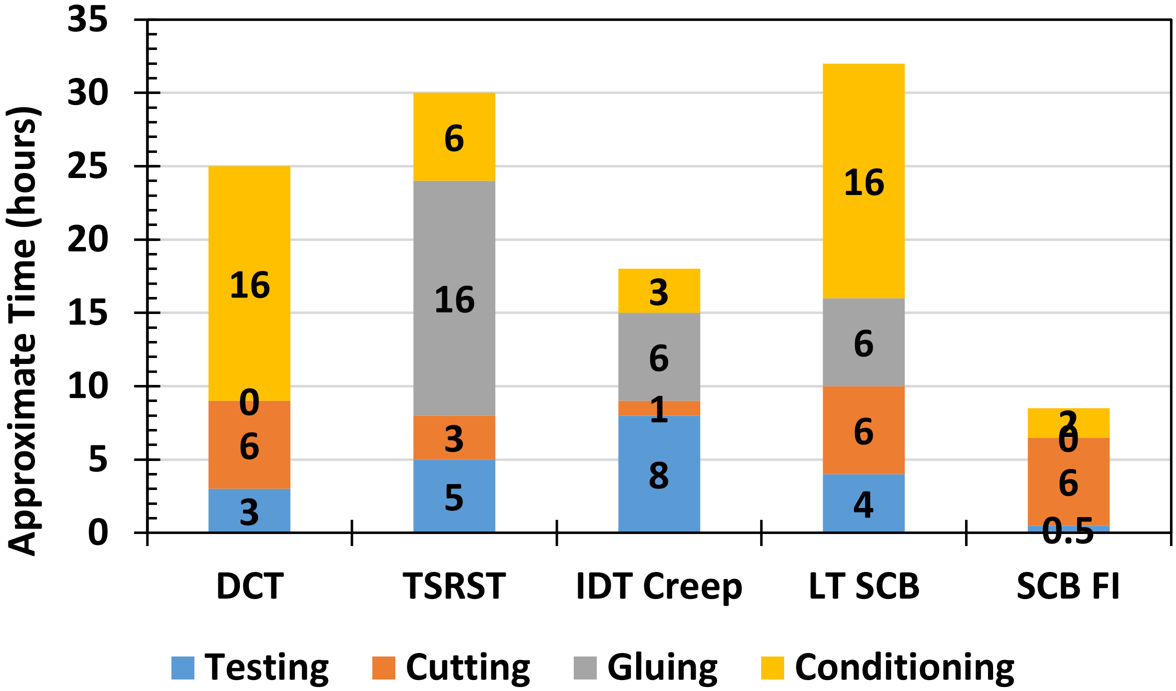


**Figure 2: Time Estimate Requirements to Conduct Thermal Cracking Test Method**

## V. Candidate Performance Tests -Rutting (Permanent Deformation) Tests

Table 4 identifies current rutting test methods available for implementation and their respective general information. Regarding expense, the cheapest test method to implement and conduct would be the High Temperature IDT (HT-IDT) test. The HT-IDT was also found to be the quickest test procedure to conduct as well (Figure 3). The most expensive test method to implement was the Asphalt Pavement Analyzer (APA when the large chamber unit is purchased). If the smaller, "table top" version, is to be purchased instead, it would have a similar cost to the Asphalt Mixture Performance Tester (AMPT) and some Hamburg Wheel Tracking (HWT) test equipment.

The time requirements vary slightly, but were found to be much quicker than most fatigue and thermal cracking tests (Figure 3). Some test procedures, such as the HWT and AMPT Flow Number, could take a considerable amount of time when test samples have significant rutting resistance.

**Table 4: Candidate Rutting Test Procedures and Their General Information**

| Test Method/Equipment | Costs | Testing Time | Total Time (after samples have been compacted) | | |
|---|---|---|---|---|---|
| | | | Cutting | Gluing | Conditioning |
| Asphalt Pavement Analyzer | $115,000 (Large); $70,000 (Junior) | 2.25 hours | N.A. | N.A. | 6 to 24 hours |
| AMPT Flow Number Test | >$70,000 | Anywhere from 0.5 to 4 hours | Up to 3 hours for 3 samples | N.A. | Up to 3 hours per sample |
| AMPT Triaxial Stress Sweep (not much information on test) | >$70,000 | Anywhere from 0.5 to 4 hours | Up to 3 hours for 3 samples | N.A. | Up to 3 hours per sample |
| Hamburg Wheel Tracking | $55,000 to $70,000 | Up to 6.5 hours | 0.5 to 2 hours for cylindrical samples | N.A. | > 1 hour (spec says 30 min.) |
| High Temperature IDT Strength | ≈ $15,000 $5,500 (SmartJig) | 3 specimens within 15 minutes | N.A. | N.A. | > 2 hours |

Assumptions:
1. Not including the costs of gyratory compactor and time associated with compacting specimens
2. Costs do not include;
   Wet saw = $6,000
   Core drill = $3,500
   Environmental Chamber = $5,000
3. Does not include time associated to bulk specimens after cutting/trimming

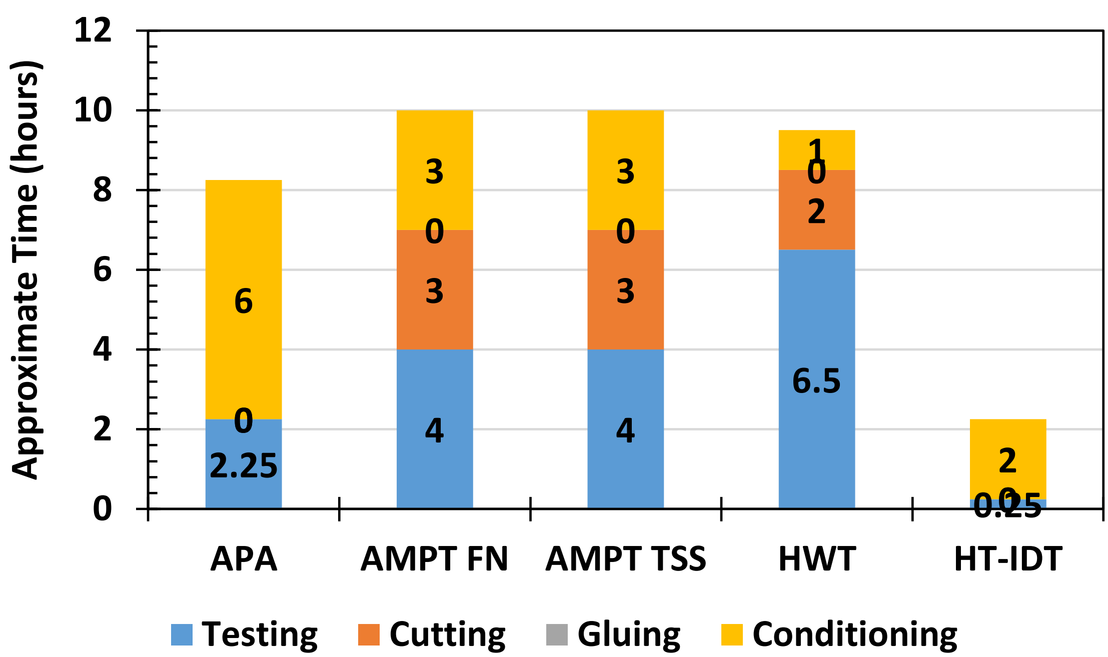


**Figure 3: Time Estimate Requirements to Conduct Rutting Test Methods**

## VI. Candidate Performance Tests - Moisture Damage (Stripping) Susceptibility and Durability

Lastly, the identified Moisture Damage Susceptibility tests methods are summarized in Table 5. The most expensive test device for moisture susceptibility was found to be the Hamburg Wheel Tracking (HWT) test. However, if a state agency decided to also use the HWT for a rutting test method, the higher expense could be justified if the same equipment was used for two different mixture distress tests. The least expensive test method was found to be the Tensile Strength Ratio (TSR) test. However, the TSR test was by far the most time-consuming test procedure due to the amount of time required to include a freeze-thaw cycle. The quickest test procedure for evaluating moisture damage potential was found to be the MiST device.

It should be noted that the Cantabro test was included as there is preliminary information that shows the method can be used to evaluate the durability of asphalt mixtures. However, due to lack of literature clearly identifying moisture damage comparisons, it was solely listed and not directly compared.

**Table 5: Candidate Moisture Damage Susceptibility Test Procedures and Their General Information**

| Test Method/Equipment | Costs | Testing Time | Total Time (after samples have been compacted) | | |
|---|---|---|---|---|---|
| | | | Cutting | Gluing | Conditioning |
| Tensile Strength Ratio | ≈ $15,000 | 0.5 to 1 hour | N.A. | N.A. | 4 to 5 days |
| MiST Device | ≈ $18,000 | Up to 6 hours for 3 specimens | N.A. | N.A. | < 2 hours |
| Cantabro | ≈ $10,000 | < 2 hours for 3 specimens | N.A. | N.A. | > 4 hours |
| Hamburg Wheel Tracking | $55,000 to $70,000 | Up to 6.5 hours | 0.5 to 2 hours for cylindrical samples | N.A. | > 1 hour (spec says 30 min.) |

Assumptions:

1. Not including the costs of gyratory compactor and time associated with compacting specimens
2. Costs do not include;
   Wet saw = $6,000
   Core drill = $3,500
   Environmental Chamber = $5,000 to $10,000
3. Does not include time associated to bulk specimens after cutting/trimming
4. Large differences in curing time for epoxies used in gluing

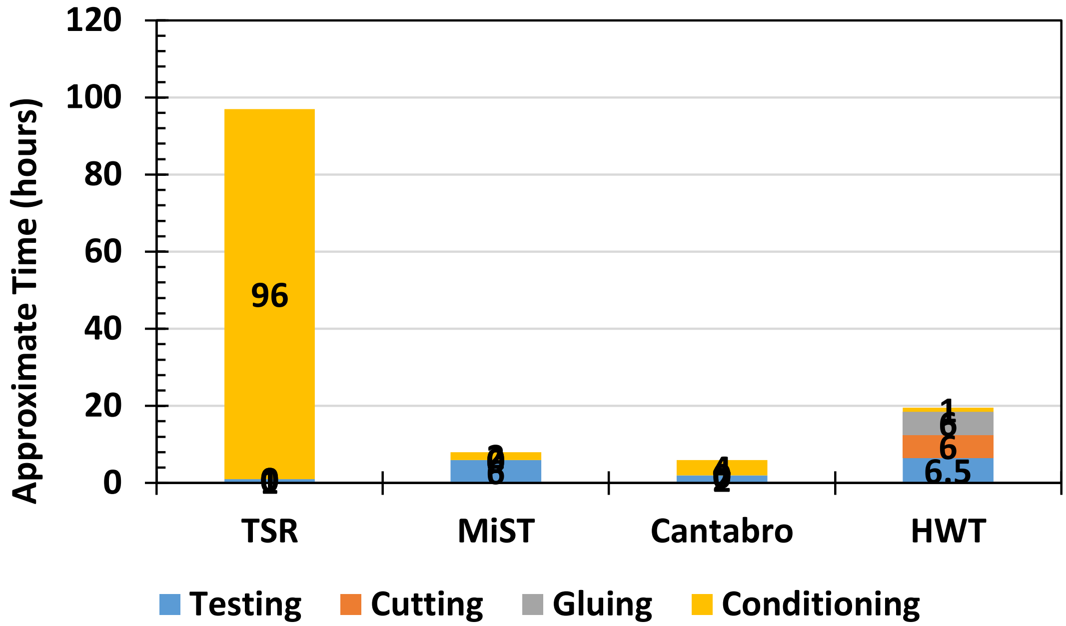


**Figure 4: Time Estimate Requirements to Conduct Moisture Damage Susceptibility Test Methods**

## VII. State Agency Current Performance Tests and Potential Roadblocks

A second, brief survey was provided to the state agencies to gain insight on the different performance testing equipment currently housed at each agency, as well as past or current research work the agencies have conducted with different test devices. The reason for the survey was concern recommending test procedures that could accrue significant costs for the state agency. Additionally, if common test procedures could be recommended, the different state agencies and testing laboratories in the Northeast could leverage performance test equipment more efficiently. Appendix A includes the Excel-based survey information requested.

Figure 5 shows the survey results regarding the current asphalt mixture performance testing capabilities of the different state agencies in the New England Transportation Consortium (NETC). The general highlights would indicate that:

- 2 of the 6 states own a universal testing machine (servo-hydraulic or screw driven). It was not noted as to whether or not the units are operating on a daily or weekly basis
- 4 of the 6 states own an Asphalt Mixture Performance Tester (AMPT)
- 4 of the 6 states own a Hamburg Wheel Tracking machine (with Connecticut DOT's at the University of Connecticut)
- 5 of the 6 states own a Marshall and Stability Flow device
- 2 of the 6 states own a standalone Semi-circular Bend (SCB) Flexibility Index device;
- 1 of 6 states (Maine) owns a MiST device for moisture susceptibility testing
- 6 of 6 states own an LA Abrasion Machine

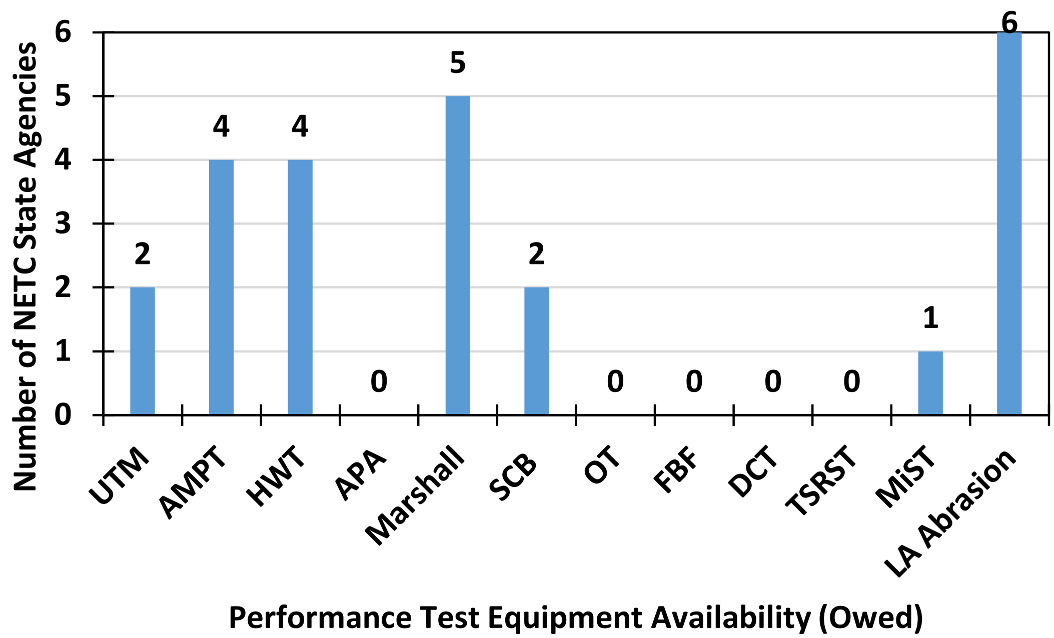


**Figure 5: Performance Test Equipment Currently Owned/Housed by NETC State Agencies**

Figure 6 shows the survey results regarding what test procedures are of immediate interest and/or being currently evaluated by the NETC state agencies. In summary, the survey indicated:

- 3 of 6 NETC state agencies have shown interest in using the Hamburg Wheel Tracking (HWT) and IDEAL-CT test procedures
- 2 of 6 NETC state agencies have shown interest in using the Asphalt Mixture Performance Tester (AMPT) and SCB Flexibility Index
- 1 of 6 NETC state agencies have shown interest in looking at the MiST device for moisture damage potential

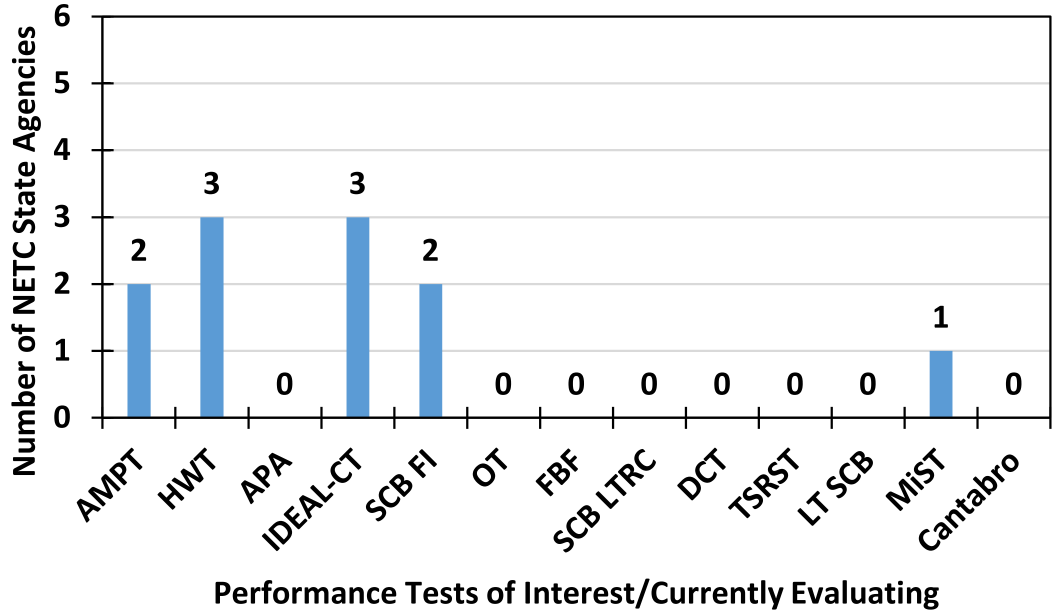


**Figure 6: Performance Test Procedures of Interest and/or Currently Evaluating by the NETC State Agencies**

Three of the six NETC state agencies leverage relationships with different universities/colleges in the northeast for performance testing and research. University of Massachusetts-Dartmouth (UMassD), University of New Hampshire (UNH), and Worchester Polytechnic Institute (WPI) were noted as having laboratories containing their own performance testing equipment or equipment loaned to them by the state agency (i.e. – UNH has an AMPT loaned to them by the New Hampshire DOT; WPI has a MiST device loaned to them by Maine DOT).

The NETC state agencies were also asked what are some foreseeable "roadblocks" that could delay the development of Performance Related Specifications (PRS) and Balanced Mixture Design (BMD). Some of the concerns noted were:

- Procurement of test equipment may take time (multiple years depending on associated costs)
- Procurement of calibration and repair services may be difficult

## VII. Final Recommendation for Candidate Performance Tests

Based on the information provided, there are a number of options for which the NETC State Agencies can take in selecting performance testing equipment for Balanced Mixture Design (BMD).

*BMD Approaches A to C (Performance Related Specifications Based)*

Based on reviewing the various survey results, the following general test procedures are recommended moving forward for Balanced Mixture Design for the NETC State Agencies:

1. Rutting
    a. With 4 of the 6 states currently having the Hamburg Wheel Tracking (HWT) device available, it would make perfect sense to include the HWT as a means of rutting potential evaluation. Selecting the HWT would minimize the number of state agencies needing to purchase new equipment, and with four agencies having the device, Round Robin testing can be conducted among the labs within the region to ensure devices are working properly.
    b. With 5 of the 6 states currently having a Marshall compression machine, inclusion of the High Temperature IDT (HT-IDT) should also be included for future evaluation. The additional benefit of the HT-IDT test is that there are minimal sample preparation requirements and testing can easily be conducted at the asphalt plant's QC laboratory with minimal investment from the asphalt plant.
2. Fatigue Cracking
    a. With 5 of the 6 states currently having a Marshall compression machine, the IDEAL-CT test procedure would result in an inexpensive solution to evaluating the fatigue cracking potential during mixture design and production.
    b. 2 of the 6 states noted they have availability of a standalone SCB device for the SCB Flexibility Index (SCB FI). In addition, the SCB FI test can be conducted on current Marshall compression machines using InstroTek's SMART SCB Jig apparatus (Figure 7) at a cost of less than $8,000 investment. Lastly, the SCB FI test can also be conducted on the AMPT with the purchase of additional attachments. However, the date of manufacture of the machine will determine whether or not this is a viable option as older AMPT machines may not be suitable for the upgraded SCB testing apparatus.

**Figure 7: InstroTek's SMART SCB Jig**

3. Thermal Cracking
    This is the most difficult of the performance tests to address as none of the NETC State Agencies noted that they owned any of the low temperature cracking test procedures. Therefore, there are a few potential options for including Thermal Cracking analysis within a Balanced Mixture Design program;
    a. Two universities in the Northeast, University of Massachusetts-Dartmouth and University of New Hampshire have the capability of currently conducting the Disk-Shaped Compact Tension (DCT) test. Without requiring the procurement of

new testing equipment and calibration/repair services, agreements with the NETC member universities can be developed for thermal cracking testing.

b. With additional research, there may be merit in evaluating SCB Flexibility Index and the IDEAL-CT and how they related to the DCT test. Figure 8 below shows some work conducted for PennDOT's Long Life Asphalt Pavement (LLAP) projects containing both 9.5 mm NMAS SMA and 19 mm NMAS dense graded asphalt mixtures. Both the DCT test at -12ºC and the SCB FI at 25ºC are required testing procedures. The results show that a relationship does exist, but perhaps could be improved by looking at different testing temperatures. Varying loading rates in the SCB FI could also be evaluated, but would eliminate the use of the Marshall compression machine from testing. Testing could be conducted during the mixture design phase using both tests to establish initial baseline. Such "surrogate" type testing would need to be conducted for each state's own materials if a database and general relationship wished to be used.

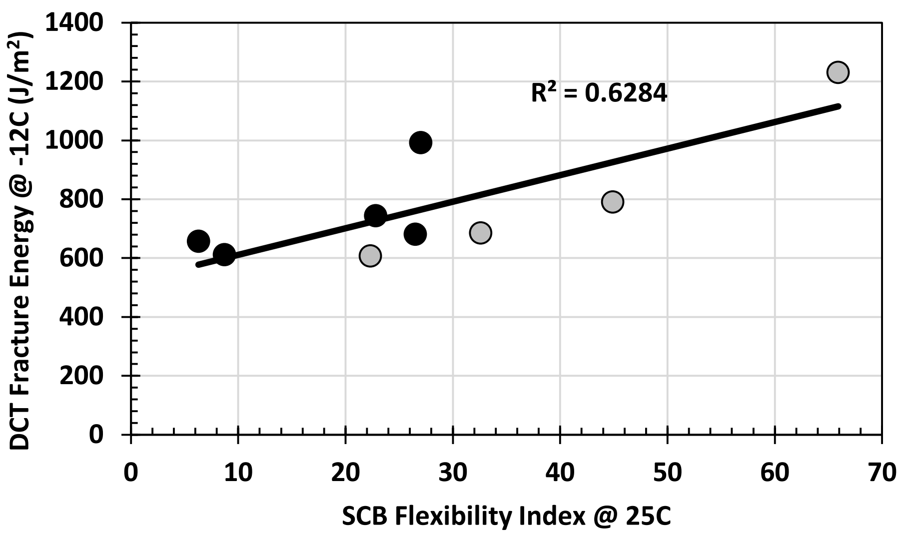


**Figure 8: Comparison of DCT and SCB FI Performance for PennDOT's LLAP Projects (Black Circles = Lab Mixed; Gray Circles = Field Cores)**

4. Moisture Damage

a. With 4 of the 6 NETC State Agencies currently having access to a Hamburg Wheel Tracking (HWT) device, it would make perfect sense that the device is used for the dual purpose of rutting and moisture damage potential.

# Appendix A

# State Survey on Performance Tests and Potential Roadblocks

| State Agency | Equipment Type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Universal Testing Machine (hydraulic, screw driven) | AMPT (If so, provide year purchased) | Hamburg Wheel Tracking | Asphalt Pavement Analyzer | Marshall Stability and Flow | SCB (Stand alone version) | Overlay Tester (Stand alone version) | DCT (Stand alone version) | Beam Fatigue (Stand alone version) | TSRST | MiST | LA Abrasion Machine |
| Connecticut | | | | | | | | | | | | |
| Maine | | | | | | | | | | | | |
| Massachusetts | | | | | | | | | | | | |
| New Hampshire | | | | | | | | | | | | |
| Rhode Island | | | | | | | | | | | | |
| Vermont | | | | | | | | | | | | |

| Additional Questions | Response(s) |
|---|---|
| Are there specific test methods you are currently looking at, either through funded research or internally? ---------------------------------> | |
| - If the anwser to above is yes, please provide the test procedure(s) in the RESPONSE areas ----------------------------------------------------> | |
| Do you use a local university for mixture testing? If so, what test procedures are tested? --------------------------------------------------------> | |
| Do you envision as issue with the procurement of new equipment and/or procurement of calibration/verification services? ------------> | |

| State Agency | Test Methods Currently Evaluating | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AMPT | Hamburg Wheel Tracking | Asphalt Pavement Analyzer | IDEAL-CT | SCB FI | Overlay Tester | Beam Fatigue | LTRC SCB | DCT | TSRST | Low Temp SCB | MiST | LA Abrasion Machine |
| Connecticut | | | | | | | | | | | | | |
| Maine | | | | | | | | | | | | | |
| Massachusetts | | | | | | | | | | | | | |
| New Hampshire | | | | | | | | | | | | | |
| Rhode Island | | | | | | | | | | | | | |
| Vermont | | | | | | | | | | | | | |