Industry Practices and Suggestions for Adjusting Asphalt Mixtures to Meet Balanced Mix Design (BMD) Specifications

Presented by:
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Federal Highway Administration (FHWA)
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Final Technical Brief
- Adjustment of Mixture Design/Job Mix Formula to Satisfy Mechanical Properties, WRSC-TB-22-01
  - Praveen Gopisetti, Harold Von Quintus, Thomas Bennert, Elie Hajj and Tim Aschenbrener
  - https://www.unr.edu/wrsc/tools/asphalt/dapt-publications
  - Simply Google: “UNR BMD FHWA”
General Approach

- Select 7 industry personnel
  - Vast experience on Balanced Mix Design (BMD)
  - Regionally diverse
  - Organizationally diverse
- Interview each over a 2-day period
  - Questions provided ahead of time so interviewee could prepare
- Conduct post interview to verify interview responses/content
- Consolidate findings and develop best practices
  - Serve as a guide to contractors planning their own experiments
  - Assist to accelerate the learning curve and facilitate implementation of BMD concepts
Overview

1. Interviewees and Their Experience
2. BMD Approach Considerations & Mechanical Testing
3. Adjustments to Asphalt Mixture Components to Satisfy BMD
4. Suggestions for Improvements Going Forward
5. Conclusions
Interviewees & Their Experience
<table>
<thead>
<tr>
<th>Names of the Interviewees</th>
<th>Current Position and Organization</th>
<th>Number of Years in Current Position</th>
<th>Positions/Experience with other Organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramon Bonaquist</td>
<td>Chief Operating Officer, Advanced Asphalt Technologies</td>
<td>24 years</td>
<td>Research Engineer, FHWA (10 years)</td>
</tr>
<tr>
<td>Andrew Hanz</td>
<td>Vice President of Technology and Research, Mathy Construction</td>
<td>8 years</td>
<td>Graduate student and Postdoctoral associate at University of Wisconsin Madison</td>
</tr>
<tr>
<td>Brian Prowell</td>
<td>Principal Engineer, Advanced Materials Services</td>
<td>15 years</td>
<td>Assistant Director- NCAT Virginia Transportation Research Council Instructor – Virginia Tech</td>
</tr>
<tr>
<td>Michael Kleames &amp; Marty McNamara</td>
<td>Quality Manager III &amp; Director of Quality Control, Granite Construction</td>
<td>7 years &amp; 21 years</td>
<td>Geotechnical consultant for private engineering firms &amp; Consultant focusing on pavement management systems and pavement design</td>
</tr>
<tr>
<td>Philip Blankenship</td>
<td>Owner and CEO, Blankenship Asphalt Tech and Training</td>
<td>4 years</td>
<td>Asphalt Institute Kentucky Transportation Cabinet Koch Industries</td>
</tr>
<tr>
<td>Greg Rose</td>
<td>Quality Manager, Barre Stone Products</td>
<td>6 years</td>
<td>Material Producer for private firms- 30 years</td>
</tr>
<tr>
<td>Pat Koester</td>
<td>Vice President (Production), Howell Paving Inc</td>
<td>17 years in current position and 28 years overall with the organization</td>
<td>Illinois DOT (District 7) – 10 years</td>
</tr>
</tbody>
</table>
Balanced Mixture Design (BMD) Approaches

- Approach A – Volumetric Design with Performance Verification
- Approach B – Volumetric Design with Performance Optimization
- Approach C – Performance Modified Volumetric Design
- Approach D – Performance Design

References:
- AASHTO PP 105-20 (2022), *Standard Practice for Balanced Design of Asphalt Mixtures*
Enormous experience by the interviewees

Each organization in table has implemented an in-house approach to incorporating BMD practices

- In some cases, it was found that a hybrid approach (combining philosophies of different approaches) work best for them

<table>
<thead>
<tr>
<th>Organization</th>
<th>States worked with on BMD Projects</th>
<th>BMD Approach</th>
<th>Number of Annual Projects/Asphalt Mixture Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Asphalt Technologies</td>
<td>Pennsylvania</td>
<td>• Approach A</td>
<td>Mostly involved in Research and Development projects. Mixture designs are typically done by producers in West Virginia.</td>
</tr>
<tr>
<td>Mathy Construction</td>
<td>Wisconsin, Minnesota, Iowa</td>
<td>• Approach A</td>
<td>30 to 40 projects.</td>
</tr>
<tr>
<td>Advanced Materials Services</td>
<td>Alabama, New Jersey, Florida, California, Arizona</td>
<td>• Approach A • Approach B • Approach C for 50% RAP mixes and also with the AASHTO Pavement ME® software for forensic analysis</td>
<td>15 to 20 projects. Multiple projects on high performance pavements (racetracks and port facility pavements).</td>
</tr>
<tr>
<td>Granite Construction</td>
<td>California</td>
<td>• Approach D</td>
<td>238,300 tons (2020 and 2021 paving seasons).</td>
</tr>
<tr>
<td>Blankenship Asphalt Tech and Training</td>
<td>Kentucky</td>
<td>• Approach A • Kentucky is still in the process of implementing BMD</td>
<td>10 to 20 projects.</td>
</tr>
<tr>
<td>Barre Stone Products</td>
<td>New York</td>
<td>• Approach A</td>
<td>25,000 to 100,000 tons a year.</td>
</tr>
<tr>
<td>Howell Paving Inc</td>
<td>Illinois</td>
<td>• Approach A • Approach B</td>
<td>Varies.</td>
</tr>
</tbody>
</table>
BMD Approach Considerations & Mechanical Testing
## Critical Volumetric Criteria & Mechanical Tests Used

- Effective asphalt-based volumetric parameters and air voids found to be most critical by all interviewees
- Mechanical tests highly influenced by regional State DOTs use
  - “Simpler the better...”

<table>
<thead>
<tr>
<th>Organization</th>
<th>Volumetric Properties</th>
<th>Mechanical Tests for Mix Design</th>
<th>Mechanical Tests for Production or QA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Asphalt Technologies</td>
<td>Air Voids, Binder Content by Volume</td>
<td>HT-IDT, IDEAL-CT</td>
<td>HT-IDT, IDEAL-CT</td>
</tr>
<tr>
<td>Advanced Materials Services</td>
<td>Air Voids, VMA, VFA</td>
<td>HWT, IDEAL-CT</td>
<td>HWT</td>
</tr>
<tr>
<td>Granite Construction</td>
<td>Air Voids, VMA, OBC, DPe</td>
<td>FN, HWT, SCB</td>
<td>FN, HWT, SCB</td>
</tr>
<tr>
<td>Blankenship Asphalt Tech and Training</td>
<td>VMA, Air Voids</td>
<td>HWT, IDEAL-RT, IDEAL-CT</td>
<td>HWT, IDEAL-RT, IDEAL-CT</td>
</tr>
<tr>
<td>Barre Stone Products</td>
<td>VMA, Air Voids, VFA</td>
<td>HT-IDT, IDEAL-RT, IDEAL-CT</td>
<td>N/A</td>
</tr>
<tr>
<td>Howell Paving Inc</td>
<td>Air Voids, VFA, VMA, Asphalt Content</td>
<td>HWT, SCB, I-FIT, TSR</td>
<td>HWT, SCB, I-FIT</td>
</tr>
</tbody>
</table>
Lack of understanding regarding impact of mixture component adjustments to final mix performance
- High degree of experience with respect to asphalt plant modifications and change in volumetrics
- How to make plant adjustments to improve rutting? Cracking?

State DOTs need to understand some volumetric criteria may need to be relaxed to achieve desired performance
- Ex. – Reduced air voids to achieve fatigue cracking, while verifying rutting resistance
- Ex. – Allow higher dust to binder for high RAP mixes when fatigue cracking passes
Primary Reason for Selecting BMD Approach to Mix Design (not in any order)

1. Practicality and simplicity ("BMD process is not that complicated")
2. Higher quality asphalt mixtures
   - Net result of better performing asphalt pavement
3. Easier to obtain high quality, standardized test equipment
4. Coordination and communication with State DOTs improved
5. Results in a better QA program with the State DOTs
6. Helps with distress specific issues
   - Ex. – Approach A found to help address NJDOT issues with
     - Composite pavement reflective cracking
     - Perpetual pavement design
     - Bridge deck waterproof overlays
## BMD Approach Considerations
### Mechanical Test Specimen Conditions, NYSDOT

### NYSDOT – Summary of Testing Criteria for Performance Engineered Mixtures (PEM)

<table>
<thead>
<tr>
<th>Test Method</th>
<th>At the Plant</th>
<th>High Temp. IDT</th>
<th>IDEAL-CT Index</th>
<th>SCB FI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gyratory Specimen Height (mm); 3 Replicates; 7 +/-1% air voids</td>
<td>High Temp. IDT</td>
<td>ASTM D6931, NCHRP 9-33</td>
<td>ASTMD8225</td>
<td>AASHTO T393</td>
</tr>
<tr>
<td>Gyratory Specimen Height (mm); 3 Replicates; 7 +/-1% air voids</td>
<td>IDEAL-CT Index</td>
<td>&lt;= 19mm 62 +/-1; &gt; 19mm 95 +/-1</td>
<td>50 +/-1</td>
<td></td>
</tr>
<tr>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
</tr>
<tr>
<td>Aging</td>
<td>Lab Mixed</td>
<td>2 hrs loose mix volumetric conditioning at compaction temp</td>
<td>4 hours loose mix volumetric conditioning at compaction temp</td>
<td>4 hours loose mix volumetric conditioning at compaction temp</td>
</tr>
<tr>
<td>Aging</td>
<td>Plant Mixed</td>
<td>Reheat loose mix to compaction temp</td>
<td>Reheat loose mix to compaction temp</td>
<td>Reheat loose mix to compaction temp</td>
</tr>
<tr>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
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<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
<td>Test Temp &amp; Conditioning (Water Bath)</td>
</tr>
</tbody>
</table>

- **Gyratory Specimen Height (mm):** 80 +/-5 mm
- **Replicates:** 3
- **Air voids:** 7 +/-1%
## BMD Approach Considerations
### –Mechanical Test Specimen Conditions, KY & CA -

<table>
<thead>
<tr>
<th>Organization</th>
<th>Item</th>
<th>Rutting</th>
<th>Cracking</th>
<th>Moisture Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blankenship Asphalt Tech &amp; Training (KY)</td>
<td>Test</td>
<td>Hamburg</td>
<td>IDEAL-CT</td>
<td>Hamburg</td>
</tr>
<tr>
<td></td>
<td>Aging Protocol</td>
<td>4 hr @ 135C (design) 2 hr @ 135C (plant after sampling)</td>
<td>4 hr @ 135C (design) 2 hr @ 135C (plant after sampling)</td>
<td>4 hr @ 135C (design) 2 hr @ 135C (plant after sampling)</td>
</tr>
<tr>
<td>Granite Construction (CA)</td>
<td>Test</td>
<td>AASHTO T378 AMPT</td>
<td>SCB Flexibility Index</td>
<td>Hamburg</td>
</tr>
<tr>
<td></td>
<td>Aging Protocol</td>
<td>Plant drop asphalt mixture in metal cans; store for 24 hrs; Reheat for 2.5 hrs and compact</td>
<td>Plant drop asphalt mixture in metal cans; store for 24 hrs; Reheat for 2.5 hrs and compact</td>
<td>Plant drop asphalt mixture in metal cans; store for 24 hrs; Reheat for 2.5 hrs and compact</td>
</tr>
</tbody>
</table>
Aging for fatigue cracking will be challenging for day-to-day operations

- Some interviewees noted impact of long-term aging can be estimated by impact of short-term aging (Bonaquist – WHRP Report, WisDOT ID No. 0092-14-06)
  - AAT – for typical materials, long-term aging not necessary – utilize agency material specifications

NCHRP Project 9-54

- Number of days of loose mix conditioning at 95°C to simulate 8 years of field aging
  - NJ: 8 days
  - WI: 5 days
  - TX: 9 to 16 days

Continuing research

- NRRA (Pooled fund program by Minnesota DOT)
- NCHRP Project 9-70 (in development)
Adjustments to Asphalt Mixture Components to Satisfy BMD

INDIVIDUAL RESPONSES/RECOMMENDATIONS
Rutting:
- Use of “Resistivity Rutting Model” provides insights into factors that significantly impact rutting
- IDT at high temperature is great for rutting assessment – fast and cheap
- Limit or reduce VMA (effective asphalt content) to reduce rutting
- Rutting decreases as RAP content increases
- Stiffer binders (PMA, RAP) will generally improve rutting resistance

Cracking:
- Effective volume of binder is generally governing factor (higher = cracking resistance)
- Pay close attention to recycled asphalt
- Cracking tests will provide justification relative to reclaimed binder ratio (RBR) and effectiveness of recycling agents
- If low temperature cracking, binder properties is predominant factor (except for case of weak aggregates)
Adjustments to Asphalt Mixture Components to Satisfy BMD –Advanced Asphalt Technologies -

- Resistivity-Rutting Model
  - Christensen and Bonaquist (2015), TRR
  - Developed from NCHRP 9-25 and 9-31
  - Includes Jnr, AV%, VMA%, gradation, Gsb, design & field compaction, aging, and ESAL traffic speed
  - Provide MESAL’s to a maximum rut depth of 12 mm (95% confidence interval)

UNR/FHWA Webinar link: https://scholarworks.unr.edu/handle/11714/8447
<table>
<thead>
<tr>
<th>Rutting:</th>
<th>Cracking:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use a polymer modified binder to improve rutting resistance</td>
<td>Add more binder &amp; increase VMA</td>
</tr>
<tr>
<td>Increase angularity of sand-sized particles</td>
<td>Increase VFA to improve overall cracking performance</td>
</tr>
</tbody>
</table>

To balance performance, reduce air voids to as low as allowed while using RAP and/or polymer to maintain stability

- Reduce air voids (as low as 2% with reasonable amount of RAP and polymer modified binder)
- Customize cracking test for needs
  - Overlay Tester for composite pavements
  - Flexural beam for flexible pavements (although high variability makes it challenging to interpret for BMD)
## Adjustments to Asphalt Mixture Components to Satisfy BMD

**– Blankenship Asphalt Tech –**

<table>
<thead>
<tr>
<th>Rutting:</th>
<th>Cracking:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Evaluate gradation combinations based on VMA and optimize JMF based on rutting mechanical test outcome</td>
<td>• Add more binder</td>
</tr>
<tr>
<td>• Lower natural sand and/or increase manufactured (angular) sand</td>
<td>• Aggregates may need to be washed (high fines content)</td>
</tr>
<tr>
<td>• Look at dust particle size – dust type matters</td>
<td>• Adjust binder type – use a softer binder</td>
</tr>
<tr>
<td></td>
<td>• Personal experience has shown IDEAL-CT may not capture full benefit of polymer, rubber, fibers and other additives – need to investigate your own materials</td>
</tr>
</tbody>
</table>

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*Lower design air void requirements when traffic conditions not major concern (i.e. – lower volumes)*
Adjustments to Asphalt Mixture Components to Satisfy BMD – Granite Construction -

- Utilizes a flowchart framework developed by UC-Davis for CalTrans
  - Change one parameter at a time to minimize confusion
  - Found some adjustments have benefitted BMD performance but was out of specification for gradation tolerances. More flexibility by agencies necessary for successful implementation
  - Experience has shown that volumetrics are not impacted by stiffness changes (i.e. – binder grade, RAP binder grade, etc.) to the same degree as mechanical tests

### Adjustments to Asphalt Mixture Components to Satisfy BMD

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**Rutting:**
- Recycled materials usually needed to meet Hamburg criterion while still being cost-effective
- Replace neat binder with PMA
- Use higher percentages of crushed sand

**Cracking:**
- Use lower range of design air voids to increase asphalt content
- Binder source makes a difference – same PG grade not always same performance
Rutting:
- If the result is close to HWT passing criterion, anti-strip is used.
- If the result is far from the passing criterion:
  - Increase PG grade
  - Modify gradation and aggregate structure to reduce VMA
  - Increased use of manufactured fines (i.e. increased angularity)

Cracking:
- Found adjustments have been mix dependent - “one size fits all” approach doesn’t work
- If stiffness type test, use a softer binder or increase VMA
- When using RAP:
  - Mechanical tests can help to optimize RAP content
  - RAP type matters
- Note: The test temperature for cracking tests should be adjusted based on geographical location (or binder grade). The adjustment can be asphalt mixture type dependent.
General Considerations when Making Adjustments

- Follow a systematic approach for making changes. One change at a time to understand impact
  - Produce sufficient mixture after adjustment to make accurate determination of impact (drum plant requires 50 to 100 tons minimum)
- Look into Bailey method concepts to define the impact on aggregate properties on effective asphalt content
  - Aggregate shape, surface texture, and packing/structure
General Considerations when Making Adjustments

- Reduce the focus on strict air void range or reduce the low-end tolerance of the air void
  - Traditional 3 to 5% plant voids; allow 2 to 5% as long as rutting passes
- Balance the use of volumetric properties and mechanical testing. Don’t focus solely on mechanical testing to solve issues
- Simple consideration – get as much asphalt in the mix until you have stability/rutting issues
  - Can counteract rutting issues with stiffer binder at high temperatures (PMA and/or recycled asphalt)
Suggestions for Improvements Going Forward
Suggestions to Improvements Moving Forward

- **Research and Training Needs**
  - A coordinated national effort to develop some type of regional/national training program
    - FHWA Balanced Mixture Design
    - NCAT BMD Guide/Lab Training
    - Virginia Education Center for Asphalt Technology (VECAT)
    - Current Youtube channel

- **A need for established training program for technicians running the mechanical tests**
  - Initiate/develop State DOT certification programs with periodic renewal
  - Encourage external training by State DOTs
  - Initiate work-force training programs at Universities

https://www.youtube.com/watch?v=5UEndoMNdGc
Suggestions to Improvements Moving Forward

- **Importance of training (industry and State level)**
  - Accreditation program for mechanical testing needed
    - AASHTO Re:source availability
      - Hamburg Wheel Tracking (AASHTO T324)
      - Asphalt Pavement Analyzer (AASHTO T340) – new for 2023
      - IDEAL-CT Index (ASTM D8225) – new for 2023

- **Which test? Impact on suppliers/contractors working in multiple states**
  - Can test relationships be established and used interchangeably?
  - Ex. Mathy Construction supplies to WI (HWT; SCB FI; IDEAL-CT), IA (HWT; DCT), MN (HWT, DCT), and IL (HWT, SCB FI)
Suggestions to Improvements Moving Forward

- If BMD adds mechanical test criteria without adding additional benefit, why bother?
  - Pay adjustments?
  - Must allow more flexibility to optimize design
  - Relax specification (Recycled asphalt content, dust to binder, gradation tolerances)

- Criteria must consider pavement conditions – tied back to structural design
  - Layer specific
  - Traffic specific
  - Similar to Superpave material selection criteria

<table>
<thead>
<tr>
<th>Test</th>
<th>NJDOT High RAP Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface Course</td>
</tr>
<tr>
<td>PG64-22</td>
<td>PG76-22</td>
</tr>
<tr>
<td>APA Rutting</td>
<td>&lt; 7 mm</td>
</tr>
<tr>
<td>Overlay Tester</td>
<td>&gt; 200 cycles</td>
</tr>
</tbody>
</table>
Conclusion

A FEW SUMMARY COMMENTS...
Although interviewees had significant experience in BMD, responses to questions identified areas where work may be needed:

- Handling variability from contractor to State DOT
- Validating lab produced vs plant produced
- Accuracy vs practicality
- Training on proper specimen fabrication and testing
- Training on impact of mixture component changes to mechanical test response (plant production)
- Accreditation program
- Round robin programs to aid in training & equipment/technician checks
- Where to collect necessary information for support
Summary

- **Mechanical testing**
  - **Rutting**
    - Minimize effective asphalt content (low end of VMA spec)
    - Increase high temp binder grade (PMA and/or recycled asphalt)
    - Increase angular/textured aggregates
  - **Cracking**
    - Increase effective asphalt content (VMA)
    - Increase VFA (increase in VMA with decrease in AV)
    - Watch impact of recycled binder
    - Binder source can impact performance with same binder grade
QUESTIONS?

Thanks!
Understanding Variability

- Variability of mechanical test is inevitable
  - Material, material and specimen preparation, testing (equipment & operator)
    - Benchmark testing your materials may help in identifying outliers
  - Asphalt mixtures are not homogeneous by nature
    - Cracking will find the path of least resistance
- Variability can be reduced by testing more replicates – but will be issue with timely results from plant production
- Generally observe lower variability for rutting tests (10 to 20% COV) when compared to cracking tests (15 to 30% COV)
- Is there a trade-off between accuracy and practicality?
  - Incorporate variability within required criteria
- Utilize round robins for variability and training
BMD Approach Considerations
– Mechanical Testing Variability –

**Impact of specimen preparation**
- Procedure needs to be well defined – concerns of over the impact of cutting, trimming, specimen dwell time, and aging on final mechanical test result
- “Follow manufacturer’s recommendation” not adequate – AASHTO T324
- Some needed to develop their own methods to minimize variability
  - Ex. – Granite Construction

Figure Source: Granite Construction


McCarthy