Optimized Mix Design Approach

ASPHALT MIXTURE AND CONSTRUCTION EXPERT TASK GROUP (ETG) MEETING, APRIL 8, 2015

FALL RIVER, MA

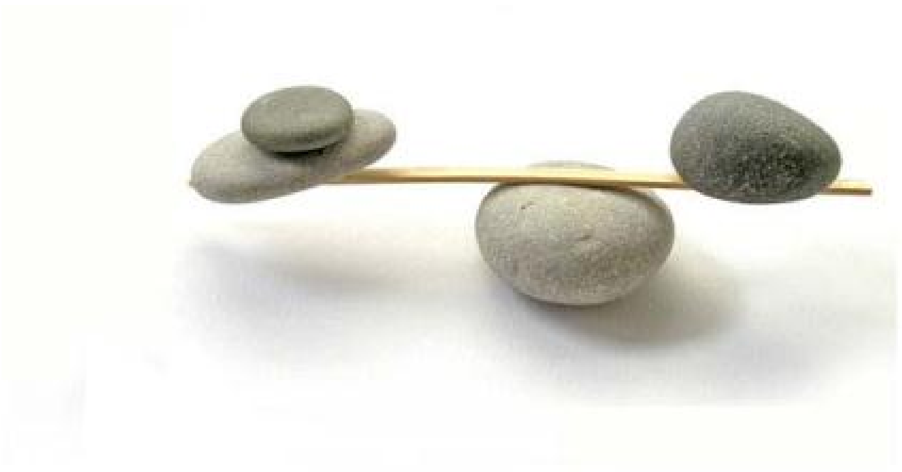
SHANE BUCHANAN

OLDCASTLE MATERIALS

Oldcastle® Materials

Discussion Topics

- Why the need for an Optimized Mix Design (OMD) Approach?
- What is currently being done in response to observed performance issues?
- What is the proposed framework for OMD?
- What are the next steps?



Why the Need for a New Mix Design Approach?

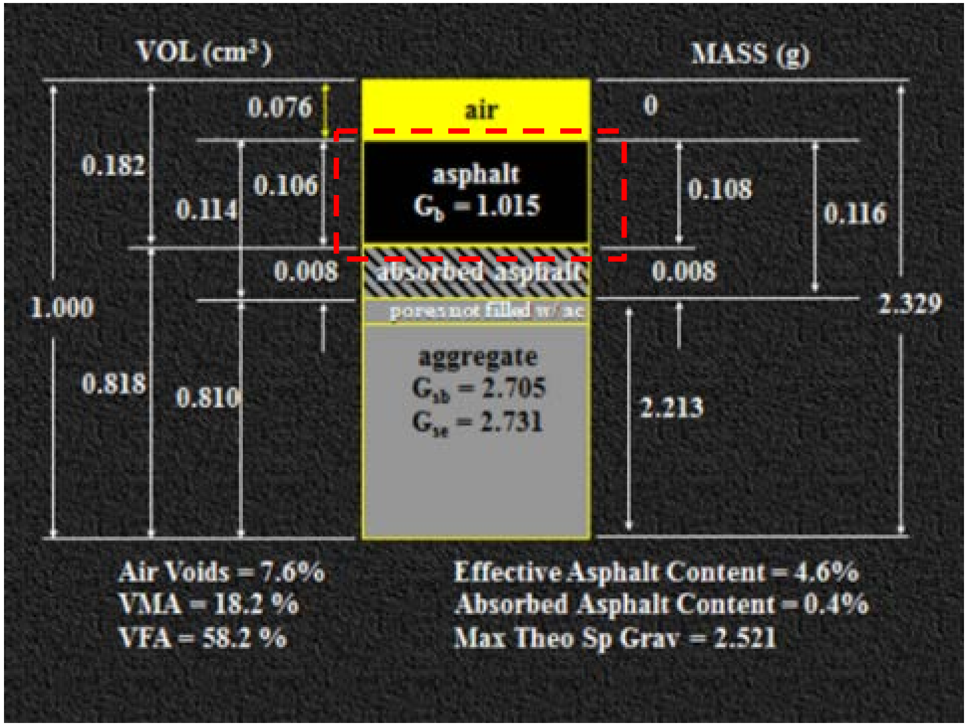
- **Continuing to increase binder replacement without addressing mix performance is not sustainable**
  - Recognize performance issues related to dry mixes exist in some areas and start working toward a solution
  - Issues are concerning to Oldcastle and the Industry
  - NAPA recently created the Pavement Performance Task Group in response to concerns
- Increase our understanding of the factors which drive mix performance to help us optimize our mixes
- Start thinking outside of long held "rules and constraints" and utilize more creativity and innovation
- Better apply the knowledge and resources that exists within the asphalt industry
- Take the lead and be a quality leader, good partner, and ***innovator***

Steps Must be Taken *Now* Towards Solutions

- Long term research is certainly needed, but we must take steps **now** towards a solution
- **Each day**, approximately 1.4 Million tons of HMA are produced in the U.S. (M-F production basis)
  - *Equivalent to ~2500 lane miles @ 12' wide and 1.5" thick*
  - *Distance from New York to Las Vegas*

Agencies Are Searching for Solutions

- **Superpave system is quickly becoming unrecognizable**
- Specifications are changing rapidly as agencies search for ways to improve durability
  - *Lowering gyrations*
  - *Increasing VMA*
  - *Lowering air voids*
  - *Lowering gyrations + Increasing VMA + Lowering air voids*
  - *Minimum film thickness*
  - *Minimum binder content by mass (non aggregate gravity adjusted)*
  - *Limiting recycle*
  - *Softer PG binders*
- **Establishing "cause and effect" is difficult to impossible**



Focus Needs to be on Obtaining the Appropriate Effective Binder Volume (Vbe) for the Given Mix and Application

Agencies are Searching for Solutions: Ndesign

- Gyration levels vary widely
- Levels are being reduced with the intent of gaining more binder content in mixes
- **Problem:** Mixes are designed to meet specifications while minimizing cost w/ lower gyrations not always equating to more binder

State	Gyration Level[1]	Notes
Alabama	**60**	All Mixes
Arkansas	50, 75, 100, 125	50, 75 (64-22), 100 (70-22), 125 (76-22)
Colorado	75, 100	100 mm diameter specimens
Connecticut	75, 100	Towns/municipalities use 50
Florida	50,65,**75,100**	Most are 75 level C and 100 level D/E
Idaho	50,75,100, 125	
Iowa	50, 60, 65, 68, 76, 86, 96, 109, 126	Original Nd levels + 3 low volume mixes levels
Kansas	**75**, 100	Researching going to 60 or 3% air voids at 75
Kentucky	50, 75, 100	
Maine	**50**, 75	50 used more within last 3 to 5 years
Massachusetts	50, **75**, **100**	75 and 100 most common
Michigan	45, 50, 76, 86, 96, 109, 126	Original Nd levels + 2 low volume mixes levels
Minnesota	40, 60, 90, 100	For <1, 1-3, 3-10, >10M ESAL
Mississippi	50, **65**, 85	
Missouri	50, 75, **80**, 100, 125	Ni and Nm still specified for 125 HV mix
Montana	**75**	Went to 75 from 100 in lieu of 100 and min. film thickness
Nebraska	40, 65, 95	40 shoulder, 65 low volume, 95 high volume
Nevada	Use Hveem	
New Hampshire	50, 75	3 to 3.5 air voids on 9.5 mm 75 gyr
New Jersey	50, **75**	50 rarely used

State	Gyration Level[1]	Notes
New Mexico	75, **100**, 125	75 low volume, 125 urban interstates, 100 res
New York	50, **75**, 100	50 and 100 rarely used
North Carolina	50, **65**, **75**, 100	50 for low volume fine 9.5 mix
Ohio	**65**	All Mixes
Oklahoma	64-22 (50), 70-28 (60) , and 76-28 (80)	Vary based on PG binder
Oregon	65, 80, 100	
Pennsylvania	50, 75, 100	
Rhode Island	**50**	DOT guides producer into gradings with higher AC; will specify H, V, E binders to combat rutting
Tennessee	**65** or 75 Marshall	
Texas	**50**	Engineer can reduce gyrations to between 35 and 50.
Utah	50, **75**, 100, 125	Mostly 75 Ndesign, 12.5 mm w/ 3.5% air voids
Vermont	50, **65**, 80	50 and 80 rarely used
Virginia	**65**	All Mixes. Researching 50 gyrations for some mixes based on Marshall C mixes w/ desire to have additional 0.2% binder.
Washington	50,75,100, 125	
West Virginia	50, 65, 80, 100	80 and 100 drop to 65 and 80, respectively if PG 76 is used or mix placed below top two lifts

Note: 1) Gyration level highlighted in "Bold" indicates main level used.

Agencies are Searching for Solutions: Example 1

- Alabama DOT
  - Nd = 60 gyrations for all mixes
  - Increased VMA + minimum total binder content for non-RAS and RAS mixes (0.2% higher) + 3.5% design voids for RAS mixes

1. AIR VOIDS (Va).
The design air voids for all levels of traffic is 3.5 % for mixes containing RAS and 4.0 % for all other mixes.

2. VOIDS IN MINERAL AGGREGATE (VMA).
The job mix shall be designed at a minimum VMA given in the following table.

VOIDS IN MINERAL AGGREGATE DESIGN VMA FOR SUPERPAVE ***		
Maximum Aggregate Size * (inches) {mm}	Nominal Aggregate Size (inches) {mm}	Minimum VMA (%)
3/8 {9.5 }	No. 4 {4.75}	16.5 **
1/2 {12.5 }	3/8 {9.5}	15.5
3/4 {19.0 }	1/2 {12.5}	14.5
1 {25.0 }	3/4 {19.0}	13.5
1.5 {37.5 }	1 {25.0}	12.5

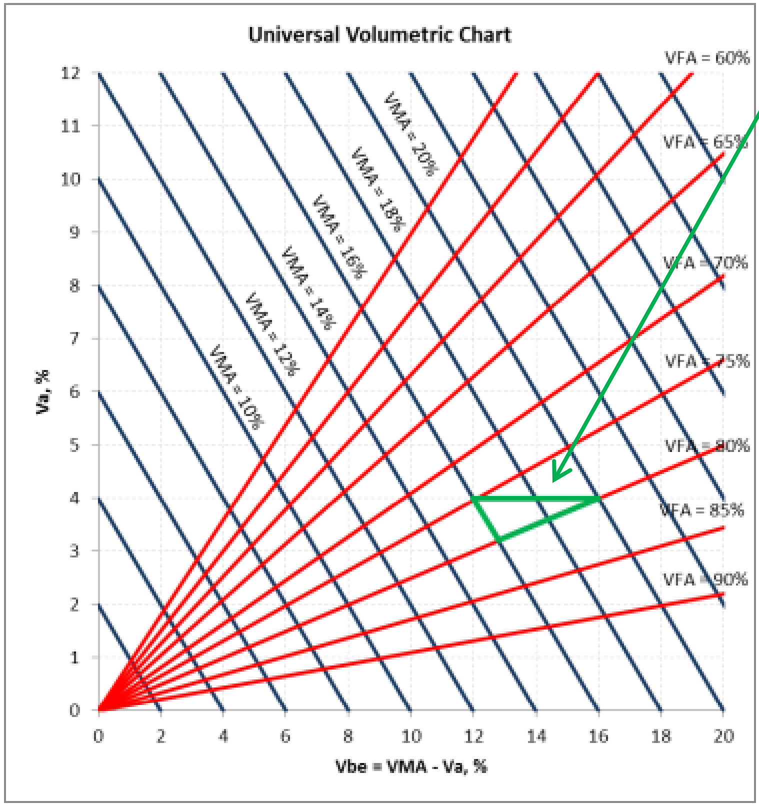
* As defined in Subarticle 424.02(c)
** All 3/8" (9.5 mm} mixes where the ESAL range is greater than A/B shall have a maximum VMA of 18.0.
*** Production VMA may be 0.5 lower than design VMA.

LIQUID ASPHALT BINDER CONTENT (Pb) CRITERIA FOR SUPERPAVE			
Maximum Aggregate Size* (inches) {mm}	Nominal Aggregate Size (inches) {mm}	Minimum Liquid Asphalt Binder Content (Pb) by Percent of Total Mix**	Minimum Liquid Asphalt Binder Content (Pb) for mixes containing RAS by Percent of Total Mix**
3/8 {9.5 }	No. 4 {4.75}	5.90	6.1
1/2 {12.5 }	3/8 {9.5}	5.50	5.7
3/4 {19.0 }	1/2 {12.5}	5.10	5.3
1 {25.0 }	3/4 {19.0}	4.40	4.6
1.5 {37.5 }	1 {25.0}	4.20	4.4

* As defined in Subarticle 424.02(d)
** Nd = 60

Agencies are Searching for Solutions: Example 2

- Virginia DOT
- Nd = 65 for all mixes



Tight Design Window

TABLE II-14
Mix Design Criteria

Mix Type	VTM (%) Production (Note 1)	VFA (%) Design	VFA (%) Production (Note 2)	Min. VMA (%)	Fines/Asphalt Ratio (Note 3)	No. of Gyrations N Design
SM-9.0A Notes 1,2,3	2.0-5.0	75-80	70-85	16	0.6-1.3	65
SM-9.0D Notes 1,2,3	2.0-5.0	75-80	70-85	16	0.6-1.3	65
SM-9.0E Notes 1,2,3	2.0-5.0	75-80	70-85	16	0.6-1.3	65
SM-9.5A Notes 1,2,3	2.0-5.0	73-79	68-84	15	0.6-1.2	65
SM-9.5D Notes 1,2,3	2.0-5.0	73-79	68-84	15	0.6-1.2	65
SM-9.5E Notes 1,2,3	2.0-5.0	73-79	68-84	15	0.6-1.2	65
SM-12.5A Notes 1,2,3	2.0-5.0	70-78	65-83	14	0.6-1.2	65
SM-12.5D Notes 1,2,3	2.0-5.0	70-78	65-83	14	0.6-1.2	65
SM-12.5E Notes 1,2,3	2.0-5.0	70-78	65-83	14	0.6-1.2	65
IM-19.0A Notes 1,2,3	2.0-5.0	69-76	64-81	13	0.6-1.2	65
IM-19.0D Notes 1,2,3	2.0-5.0	69-76	64-81	13	0.6-1.2	65
IM-19.0E Notes 1,2,3	2.0-5.0	69-76	64-81	13	0.6-1.2	65
BM-25.0A Notes 2,3,4	1.0-4.0	67-87	67-92	12	0.6-1.3	65
BM-25.0D Notes 2,3,4	1.0-4.0	67-87	67-92	12	0.6-1.3	65

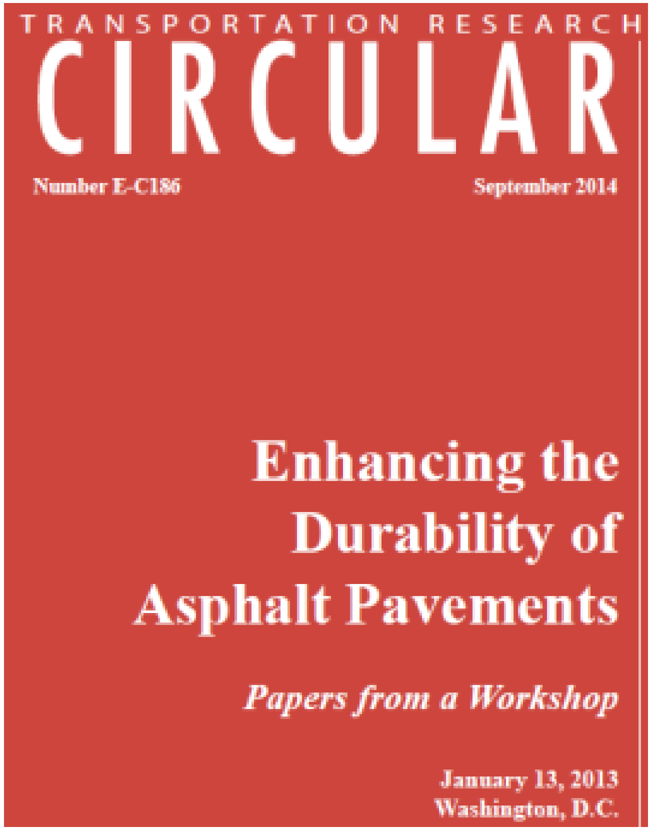
[1]SM = Surface Mixture; IM = Intermediate Mixture; BM = Base Mixture.
Note 1: Asphalt content should be selected at 4.0 % Air Voids.
Note 2: During production of an approved job mix, the VFA shall be controlled within these limits.
Note 3: Fines-asphalt ratio is based on effective asphalt content.
Note 4: Base mix shall be designed at 2.5% air voids. BM-25.0A shall have a minimum asphalt content of 4.4% unless otherwise approved by the Engineer. BM-25.0D shall have a minimum asphalt content of 4.6% unless otherwise approved by the Engineer.

Enhancing the Durability of Asphalt Pavements

Impact of Mix Design on Asphalt Pavement Durability

RAMON BONAQUIST
Advanced Asphalt Technologies, LLC

- "**VBE is the primary mixture design factor affecting both durability and fatigue cracking resistance**. Durability and fatigue resistance improve with increasing VBE."
- "**Stone matrix asphalt (SMA) mixtures**, which are considered to be extremely durable and crack resistant, **have the highest minimum design VBE**."
- "The mix design manual developed in NCHRP Project 9-33 recommends that agencies should consider **increasing the design VMA by 1.0%** "to obtain mixtures with increased asphalt binder content, which can improve field compaction, fatigue resistance, and general durability"
- "A number of state highway agencies have **decreased the design gyration levels** in an attempt to increase effective binder contents. However, **decreasing the design gyrations may not always produce mixtures with higher VBE.** If a producer is able to change gradation or the source of some of the aggregates in the mixture, **it may be possible to remain near the minimum design VBE at the lower gyration level."**


TRANSPORTATION RESEARCH
CIRCULAR
Number E-C186 September 2014
Enhancing the Durability of Asphalt Pavements
Papers from a Workshop
January 13, 2013
Washington, D.C.

Mix Design Approaches - Balanced

- Balanced Mix Design Approaches are Currently Utilized by Some Agencies
  - Texas (Hamburg + OT)
  - Louisiana (Hamburg + SCB)
  - New Jersey (APA + OT)
- **Questions**
  - While the utilized balanced approach design may be an improvement, is it appropriate for all mixes?
    - For example,
      - 1) Are universal volumetrics (e.g., VMA and air voids) controlling without regard to traffic?
      - 2) Are the utilized performance tests appropriate for the probable mode of distress?

Mix Design Approaches

- **Indiana**: Matching design and field compaction (5-5)
  - Key points….
    - Target 5% air voids for lab and field compaction
    - Ndesign of 50
    - M323 Vbe used (VMA – Va @ 4%)
      - Drive up liquid and adjust aggregate structure accordingly.
- Improved stiffness compared to M323 designs @ Nd = 100 and 7% field air voids.

Optimized Mix Design Overview

Evolution of Mix Design

1890

- **Barber Asphalt Paving Company**
- Asphalt cement 12 to 15% / Sand 70 to 83% / Pulverized carbonite of lime 5 to 15%

1905

- **Clifford Richardson, New York Testing Company**
- Surface sand mix: 100% passing No. 10, 15% passing No. 200, 9 to 14% asphalt
- Asphaltic concrete for lower layers, VMA terminology used, 2.2% more VMA than current day mixes or ~0.9% higher binder content

1920s

- **Hubbard Field Method** (Charles Hubbard and Frederick Field)
- Sand asphalt design
- 30 blow, 6" diameter **with compression test (performance)** asphaltic concrete design (Modified HF Method)

1927

- **Francis Hveem** (Caltrans)
- Surface area factors used to determine binder content; **Hveem stabilometer and cohesionmeter** used
- Air voids not used initially, mixes generally drier relative to others, fatigue cracking an issue

1943

- **Bruce Marshall**, Mississippi Highway Department
- Refined Hubbard Field method, standard compaction energy with drop hammer
- Initially, only used air voids and VFA, VMA added in 1962; **stability and flow utilized**

1993

- **Superpave**
- Level 1 (volumetric)
- Level 2 and 3 (performance based, but **never implemented**)

http://asphaltmagazine.com/history-of-asphalt-mix-design-in-north-america-part-2/

Conventional Mix Design Thoughts

- Largely **recipe driven** based on what we think works
  - Items specified
    - Aggregates (via spec. property requirements)
    - Blend grading
    - Volumetrics
      - Air voids, VMA, VFA, Dust/Aceff, film thickness, etc.
    - PG binder type and minimum amount in some cases
    - RAP and/or RAS content
    - Other additives use and amount

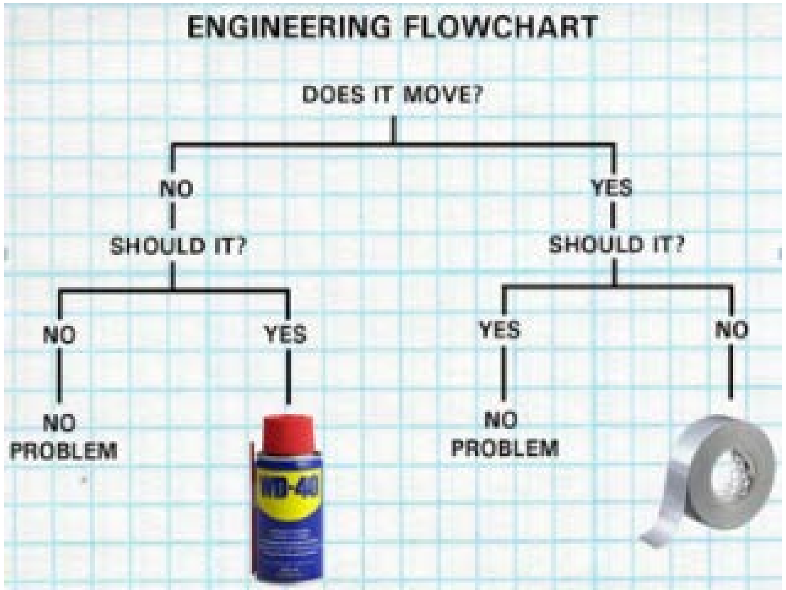
"Marshall method" pavement testing apparatus

gsl.erdc.usace.army.mil/gl-history/Chap3.htm

- **Problem….**
  - Recipe specifications have become convoluted and confounded over time with ***specified items competing against each other to achieve the desired goals***
    - New requirements get added and nothing gets removed
    - Innovation has become stifled with our knowledge outpacing specifications

Optimized Mix Design: A Better Approach

- Let’s stop using a recipe to “bake the cake”.
- Define what you want in the cake and open up the recipe to meet the end result.
  - What defines a good cake? Good Taste
  - What defines a good mix? **Optimized Performance**
- Optimized Mix Design Approach Foundational Points
  - **“Use what works”**
  - **“Eliminate what doesn’t”**
  - **“Be simple and practical”**
- Build on our existing knowledge foundation.
  - “Good doesn’t have to be complicated and complicated isn’t always good.”

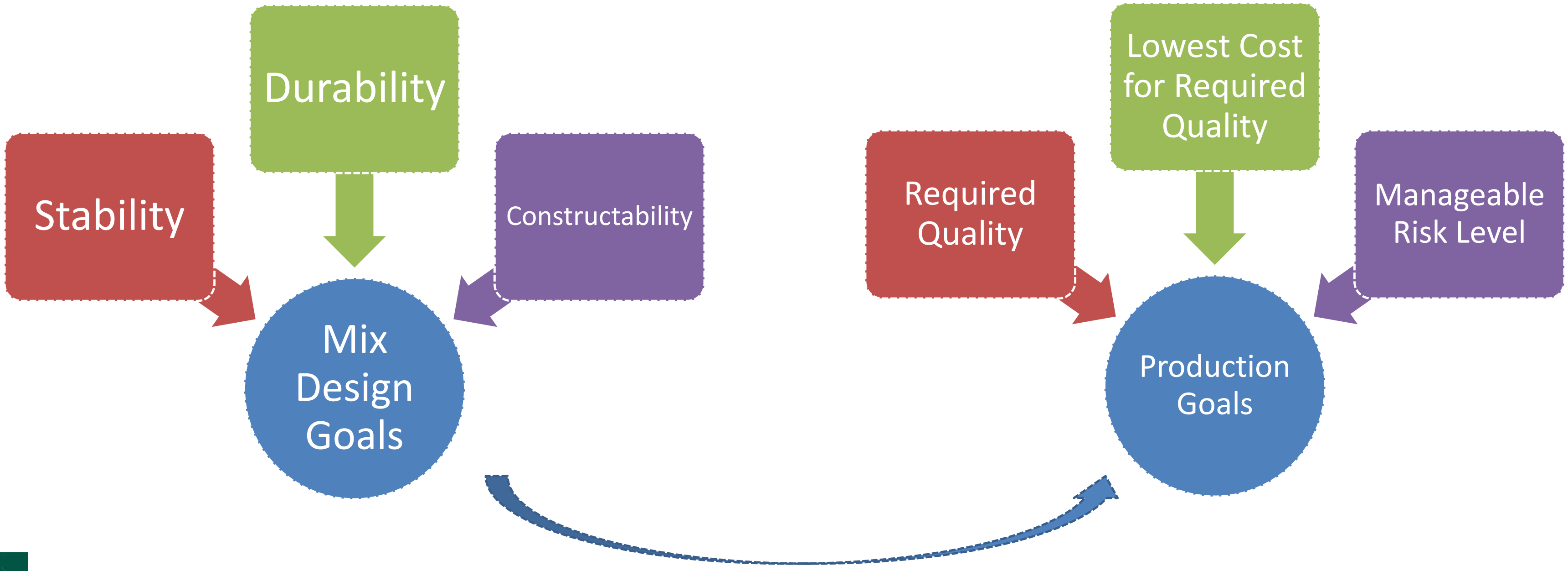


What is a “Good” Mix Design?

- Depends on how we define “Good”.
- “Good” is not defined by any ***one*** of these factors alone
  - Cheap or Expensive
  - Simple or Complex
  - Empirical or Theoretical (Mechanistic)
  - Quick or Slow to design
  - Virgin or High Binder Replacement
  - Workable or Harsh
  - Consistent or Erratic properties
  - Zero penalties or Abundant penalties
- A “good” mix must be at least partially defined as one that meets the requirements of the job (specification compliance and/or customer expectations, and performance) while being designed using an optimized approach which considers cost.

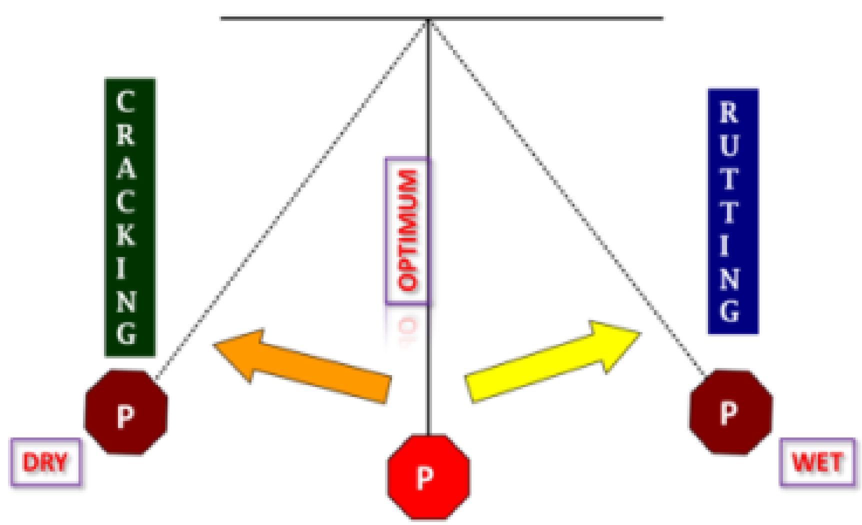
Optimized Mix Design Mix Design and Production Goals

- An optimized design approach should yield a mix which meets the mix design and production goals.



Optimized Mix Design Approach – Basic Fundamentals

- A mix needs appropriate binder to have good stability (resist rutting) and durability (resist cracking) performance
  - A given mix may have many "design" binder contents, but only one "optimum"
- **Must move away from the philosophy of "putting as little binder in the mix as possible just to limit cracking"**
- Greatly limit the "rules" for the mix designer
  - Eliminate/reduce restrictions for
    - Recycle,
    - Aggregate blend grading,
    - Aggregate,
    - PG binder,
    - Volumetrics
    - Focus on the end result of **PERFORMANCE**



Optimized Mix DesiGn Approach (OMEGA)

I
- Material Evaluation and Selection

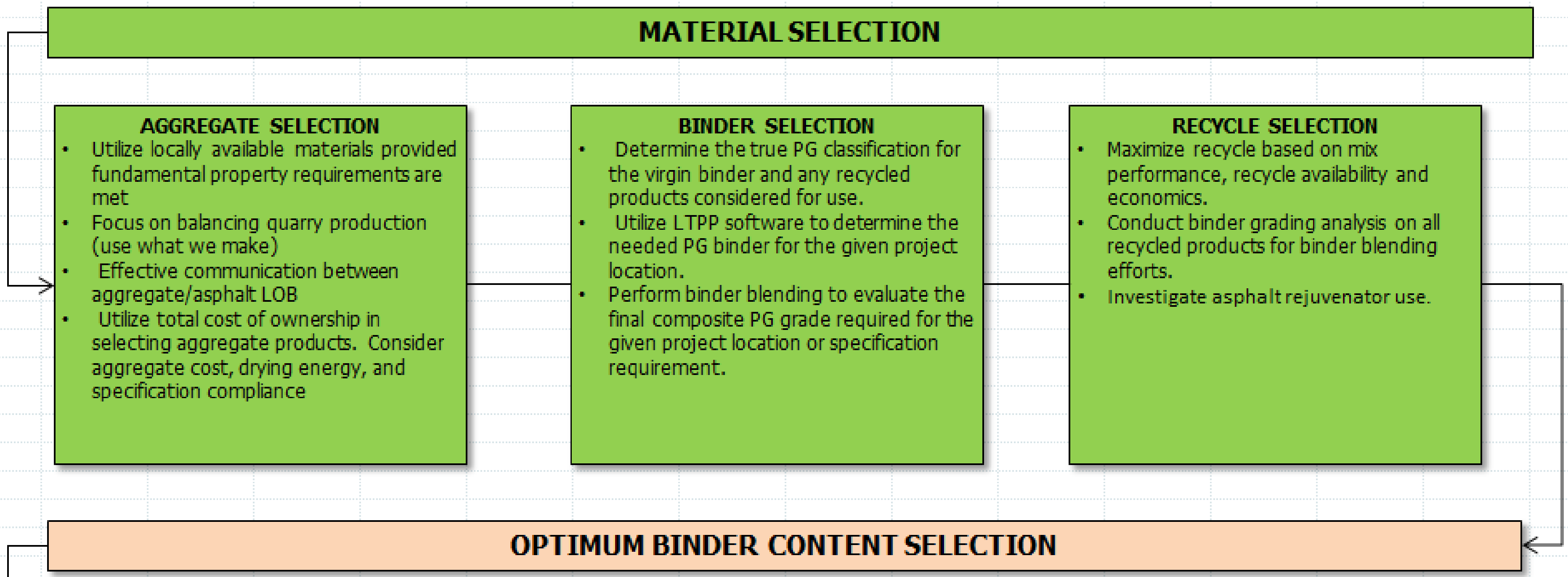
II
- Mixture Stability Performance Evaluation

III
- Mixture Durability Performance Evaluation

IV
- Mixture Workability Evaluation

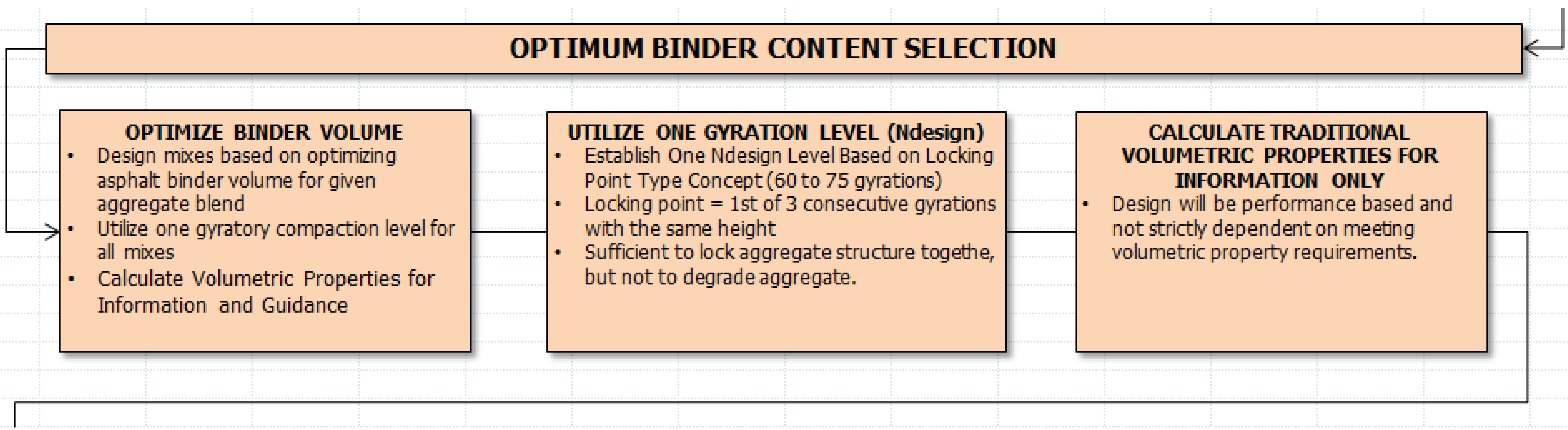
Optimized Mix Design Approach – Framework

- **Material Evaluation and Selection**
  - Emphasis on using **local materials, maximizing recycle, and engineering the binder** for the given application while keeping performance in mind
  - Increased awareness and focus needed on importance of material properties (e.g., RAP aggregate gravity and recycled binder continuous grading)



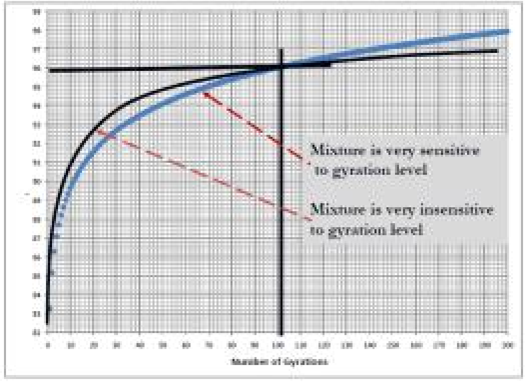
Optimized Mix Design Approach – Framework

- **Optimum Binder Content Selection (Key Points)**
  - Design based on volume w/ a single gyration level used (e.g., locking point), 60 to 75 gyrations is typical
    - **Understand that gyration level does actually control binder content**
    - **Stop breaking aggregate during compaction and establishing unrealistic and unnecessary targets for field.**
  - Volumetrics calculated for information purposes



Optimized Mix Design Approach – Framework

- Locking point or point where aggregate structure is "established" will obviously vary.
  - **1st of 3 consecutive,** 1st of 2 consecutive, 3-2-2, etc.
- Agencies are typically using 60 to 75 gyrations for most of their designs, which is in the "range" of locking point determinations.
- Establish for a given mix in consideration
- Compact specimens at Pb based on Vbe for anticipated traffic.



Optimized Mix Design Approach – Framework

- **Optimum Binder Content Selection**
  - Estimate **target effective binder volume (Vbe)** based on NMAS and traffic level
    - Smaller NMAS and lower traffic mixes need more binder
  - Adjust virgin binder content as a function of RAP and RAS addition to compensate for lack of 100% recycled binder contribution
  - Conduct mix design compaction at four binder contents (Vbe min, Vbe min-0.50, Vbe min - 1.0, Vbe min + 0.50)

ASPHALT BINDER % DETERMINATION

1. Estimate target binder content (by mass) based on achieving target minimum volume of effective binder (Vbe) for various NMAS as below:

NMS	Target Minimum Binder Volume at Traffic Level		
	Low	Medium	High
4.75	13.0	12.5	12.0
9.5	12.0	11.5	11.0
12.5	11.0	10.5	10.0
19	10.0	9.5	9.0
25	9.0	8.5	8.0
37.5	8.0	7.5	7.0

Traffic Level	Typical Roadway Applications
Low	Local roads, county roads, and city streets with minimal to no truck traffic. Driveways and light duty parking lots.
Medium	Collector roads, access streets, two lane, some multilane divided highways
High	Higher volume multilane highways, Interstates, toll highways, and heavy duty parking lots

2. Conduct mix design compaction at four binder contents (Vbe min, Vbe min-0.50, Vbe min - 1.0, Vbe min + 0.50.

Vbe Adjustment for Recycle

Recycle mixes will likely require additional considerations to help ensure sufficient Vbe is present. Options include adding additional virgin binder or rejuvenators to gain more effective binder from the recycle. Economics of both approaches should be evaluated along with the subsequent performance testing.

1. Make virgin binder addition adjustment to compensate for lack of 100% binder contribution from recycle products

Initial Rule of Thumb

Additional Virgin Binder % = 0.005 (RAP%) + 0.055 (RAS%)

Based on assumption that 90 and 70% of RAP and RAS binder contributes, respectively.

2. Utilize rejuvenators to increase the effective binder content from the recylce products.

Initial Vbe Estimation

- As starting point, utilize the M323 VMA requirement to drive the required Vbe for high volume mixes.
- Increase the Vbe by 0.5 and 1.0% for medium and low volume traffic respectively.
  - **0.2% Vbe ~ 0.1% Pbe**
- Calculate the Pbe (mass) based on the aggregate blend Gsb value
  - ***CRITICAL*** to have accurate Gsb on blend.

NMS	M323 VMA	Air Voids	VMA Target at Traffic Level			Target Minimum Binder Volume at Traffic Level			Estimated Effective Binder Content (Pbe) @ Gsb = 2.65		
			Low	Medium	High	Low	Medium	High	Low	Medium	High
4.75	16	4	17	16.5	16	13.0	12.5	12.0	5.69	5.46	5.22
9.5	15	4	16	15.5	15	12.0	11.5	11.0	5.22	4.99	4.75
12.5	14	4	15	14.5	14	11.0	10.5	10.0	4.75	4.52	4.29
19	13	4	14	13.5	13	10.0	9.5	9.0	4.29	4.06	3.83
25	12	4	13	12.5	12	9.0	8.5	8.0	3.83	3.61	3.39
37.5	11	4	12	11.5	11	8.0	7.5	7.0	3.39	3.17	2.94

Total Binder Estimation from Vbe

- Total binder content (Pb) can then be estimated using basic volumetrics.

	Binder Content Required for Target Effective Binder Volume	
	Property/Parameter	**Value**
INPUT	Aggregate Blend Bulk Specific Gravity, Gsb	2.650
	Aggregate Blend Effective Specific Gravity, Gse	2.675
	Target Minimum Volume of Effective Binder (Vbe min), %	11.0
CALC	Effective Binder Content (Pbe @ Vbe min), %	**4.75**
	Absorbed Binder Content (Pba @ Vbe min), %	**0.36**
	Total Binder Content @ Vbe min, %	**5.09**

Recycle Binder Adjustment

- **Assumption:** 90 and 70%, respectively of the RAP and RAS binder effectively contributes to the total mix binder.
  - Is this correct? No one knows, but common sense says not all binder is contributing.
- What is the impact from this adjustment?
  - At the surface, there is an obvious increase in virgin liquid cost
  - However, optimized mix design approach could open the door for more creativity and innovation which would offset cost and potentially yield more savings.

Vbe Adjustment for Recycle

Recycle mixes will likely require additional considerations to help ensure sufficient Vbe is present. Options include adding additional virgin binder or rejuvenators to gain more effective binder from the recycle. Economics of both approaches should be evaluated along with the subsequent performance testing.

1. Make virgin binder addition adjustment to compensate for lack of 100% binder contribution from recycle products

Initial Rule of Thumb

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Based on assumption that 90 and 70% of RAP and RAS binder contributes, respectively.

2. Utilize rejuvenators to increase the effective binder content from the recylce products.

20% RAP Comparison (100% and 90% Binder Contribution)

	Recycle Value Illustrator	
INPUT	**Materials and Mix Characteristics**	
	RAP Binder Content, %	5.0
	RAS Binder Content, %	20.0
	Effective RAP Binder Contribution, %	100.0
	Effective RAS Binder Contribution, %	100.0
	Total Mix Asphalt Binder Content, %	5.5
	Material Costs	
	Virgin Asphalt Binder Cost / Ton, $	500.00
	Virgin Aggregate Blend Cost, $	10.00
	RAP Cost / RAP Ton, $	8.00
	RAS Cost / RAS Ton, $	20.00
CALCULATED	**Material Costs (As Used in Mix)**	
	RAP Cost / Mix Ton, $	1.60
	RAS Cost / Mix Ton, $	0.00
	RAP + RAS Cost / Mix Ton, $	1.60
	Binder Replacement	
	RAP Binder Provided, %	1.00
	RAS Binder Provided, %	0.00
	Total Recycle Binder Provided, %	1.00
	Binder Replacement from Recycled, %	18.18
	Savings	
	RAP Net Savings / Mix Ton, $	5.30
	RAS Net Savings / Mix Ton, $	0.00
	RAP + RAS Net Savings / Mix Ton, $	5.30
INPUT	RAP %	20
	RAS %	0

	Recycle Value Illustrator	
INPUT	**Materials and Mix Characteristics**	
	RAP Binder Content, %	5.0
	RAS Binder Content, %	20.0
	Effective RAP Binder Contribution, %	90.0
	Effective RAS Binder Contribution, %	100.0
	Total Mix Asphalt Binder Content, %	5.5
	Material Costs	
	Virgin Asphalt Binder Cost / Ton, $	500.00
	Virgin Aggregate Blend Cost, $	10.00
	RAP Cost / RAP Ton, $	8.00
	RAS Cost / RAS Ton, $	20.00
CALCULATED	**Material Costs (As Used in Mix)**	
	RAP Cost / Mix Ton, $	1.60
	RAS Cost / Mix Ton, $	0.00
	RAP + RAS Cost / Mix Ton, $	1.60
	Binder Replacement	
	RAP Binder Provided, %	0.90
	RAS Binder Provided, %	0.00
	Total Recycle Binder Provided, %	0.90
	Binder Replacement from Recycled, %	16.36
	Savings	
	RAP Net Savings / Mix Ton, $	4.80
	RAS Net Savings / Mix Ton, $	0.00
	RAP + RAS Net Savings / Mix Ton, $	4.80
INPUT	RAP %	20
	RAS %	0

RAP Savings Impact

- Lost savings ($0.50/ton) from using 90% effective RAP binder contribution can be recovered by using a relatively small amount more RAP.
- 23% vs 20% in this example.
  - 23% @ 90% contribution = $5.52 compared to $5.30 (20% at 100% contribution)

RAP Savings (Binder + Aggregate)"What If" Table - RAP Eff. Binder Cont.

Net Savings *$ 4.80*	Effective Binder Contribution From RAP, %										
RAP, %	**50.0**	**55.0**	**60.0**	**65.0**	**70.0**	**75.0**	**80.0**	**85.0**	**90.0**	**95.0**	**100.0**
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	2.10	2.29	2.48	2.66	2.85	3.04	3.23	3.41	3.60	3.79	3.98
16	2.24	2.44	2.64	2.84	3.04	3.24	3.44	3.64	3.84	4.04	4.24
17	2.38	2.59	2.81	3.02	3.23	3.44	3.66	3.87	4.08	4.29	4.51
18	2.52	2.75	2.97	3.20	3.42	3.65	3.87	4.10	4.32	4.55	4.77
19	2.66	2.90	3.14	3.37	3.61	3.85	4.09	4.32	4.56	4.80	5.04
20	2.80	3.05	3.30	3.55	3.80	4.05	4.30	4.55	***4.80***	5.05	5.30
21	2.94	3.20	3.47	3.73	3.99	4.25	4.52	4.78	5.04	5.30	5.57
22	3.08	3.36	3.63	3.91	4.18	4.46	4.73	5.01	5.28	5.56	5.83
23	3.22	3.51	3.80	4.08	4.37	4.66	4.95	5.23	5.52	5.81	6.10
24	3.36	3.66	3.96	4.26	4.56	4.86	5.16	5.46	5.76	6.06	6.36
25	3.50	3.81	4.13	4.44	4.75	5.06	5.38	5.69	6.00	6.31	6.63
26	3.64	3.97	4.29	4.62	4.94	5.27	5.59	5.92	6.24	6.57	6.89
27	3.78	4.12	4.46	4.79	5.13	5.47	5.81	6.14	6.48	6.82	7.16
28	3.92	4.27	4.62	4.97	5.32	5.67	6.02	6.37	6.72	7.07	7.42
29	4.06	4.42	4.79	5.15	5.51	5.87	6.24	6.60	6.96	7.32	7.69
30	4.20	4.58	4.95	5.33	5.70	6.08	6.45	6.83	7.20	7.58	7.95
31	4.34	4.73	5.12	5.50	5.89	6.28	6.67	7.05	7.44	7.83	8.22
32	4.48	4.88	5.28	5.68	6.08	6.48	6.88	7.28	7.68	8.08	8.48
33	4.62	5.03	5.45	5.86	6.27	6.68	7.10	7.51	7.92	8.33	8.75
34	4.76	5.19	5.61	6.04	6.46	6.89	7.31	7.74	8.16	8.59	9.01
35	4.90	5.34	5.78	6.21	6.65	7.09	7.53	7.96	8.40	8.84	9.28
36	5.04	5.49	5.94	6.39	6.84	7.29	7.74	8.19	8.64	9.09	9.54
37	5.18	5.64	6.11	6.57	7.03	7.49	7.96	8.42	8.88	9.34	9.81
38	5.32	5.80	6.27	6.75	7.22	7.70	8.17	8.65	9.12	9.60	10.07
39	5.46	5.95	6.44	6.92	7.41	7.90	8.39	8.87	9.36	9.85	10.34
40	5.60	6.10	6.60	7.10	7.60	8.10	8.60	9.10	9.60	10.10	10.60

Optimized Mix Design Approach – Economics

- **A performance based system greatly enhances the mix designer's ability to utilize creative thinking and innovative concepts and creative thinking.**
  - Knowledge and experience may be outpacing specifications in some areas

- Asphalt demand for mixes may increase using an optimized mix design approach; however, the cost can potentially be offset by many items.
  - Local aggregate materials
  - Capped aggregate products
  - Alternate blend gradings
  - Alternate binders
  - Optimized use of recycled products (RAP, RAS, GTR, etc.)
  - Additives (WMA, rejuvenators, etc.) use
  - "XYZ Technology of Tomorrow"

- **Performance must be achieved without question or exception.**

Optimized Mix Design Approach – Framework

- **Check Stability**
  - Utilize one of several available "rutting" evaluation tools.
  - Failure criteria based on best available research (local, regional, or national)

MIX PERFORMANCE EVALUATION

CHECK STABILITY

DETERMINE RESISTANCE TO RUTTING
- Conduct testing with the asphalt pavement analyzer, Hamburg wheel tracker, or other accepted permanent deformation test
- Set pass/fail criteria based on desired performance and placement within the pavement system.

Utilize Locally Established Test Procedures
1. Hamburg
2. Asphalt Pavement Analyzer
3. AMPT Flow Number

Asphalt Pavement Analyzer
- AASHTO T340
- Maximum rut depth = 7 mm @ 8,000 cycles.

Hamburg Wheel Tracker
- AASHTO T324
- Maximum rut depth of 12.5 mm @ 20,000 cycles

- **Accelerated Mix Performance Test (AMPT)**
- AASHTO TP79
- Test temperature at 50% high pavement temperature reliability
- 20 mm depth for surface courses and top of pavement layer for intermediate andbase

Design Traffic, Million ESAL	HMA[1]	WMA[1]
< 3	--	--
3 to < 10	50	30
10 to < 30	190	105
> 30	740	415

[1] HMA conditioned 4 hours at 135 °C, WMA conditioned 2 hours at field compaction temperature.

Optimized Mix Design Approach – Framework

- **Check Durability**
  - Utilize one of many available “cracking” evaluation tools based on distress of interest
  - Failure criteria based on best available research (local, regional, or national)

CHECK DURABILITY

DETERMINE RESISTANCE TO CRACKING
- Conduct testing using the bending beam fatigue, semi circular bend, disk shaped compression, etc.
- Set pass/fail criteria based on desired performance and placement within the pavement system

Utilize Locally Established Test Procedures
1. Bending Beam Fatigue
2. Semi Circular Bend (SCB)
3. Disk Shaped Comact Tension (DCT)
4. Indirect Tensile Fracture Energy

Bending Beam Fatigue
AASHTO T321
- Target strain test level based on depth of mix from final surface
- Test at multiple strain levels to establish fatigue life curve
- Minimum 100,000 fatigue cycles to failure

Semi Circular Bend
- Test at 25C and 0.5 mm/min vertical loading rate
- Minimum fracture resistance (Jc),(no formal design criteria established)

Optimized Mix Design Approach – Framework

- **Check Durability (cont.)**
  - *Cracking prediction is a known "weak" link in performance testing*
  - *No general consensus on what is the best test or the appropriate failure threshold.*

Disk Shaped Compact Tension(DCT)

- ASTM D7313
- Test at PG low temperature + 10C
- Minimum fracture energy (J/m2) vs. traffic level (from Iowa DOT)
- < 10M ESAL = 400
- 10 to 30M ESAL = 460
- >30M ESAL = 690

Indirect Tensile Energy Ratio and Fracture Energy

- NCAT/Florida test method
- Conduct at 10C
- Energy ratio requirements

Traffic: (ESALs/yr)	Minimum Energy Ratio
< 250,000	1
< 500,000	1.3
< 1,000,000	1.95

- Fracture Energy, kJ/m3, (no formal design criteria established)

What is the Appropriate Cracking Test?

- The search continues……

NCHRP 09-57 [Active]

Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures

Project Data	
Funds:	$250,000
Staff Responsibility:	Edward T. Harrigan
Research Agency:	Texas A&M Transportation Institute
Principal Investigator:	Fujie Zhou
Effective Date:	9/1/2014
Completion Date:	3/1/2016

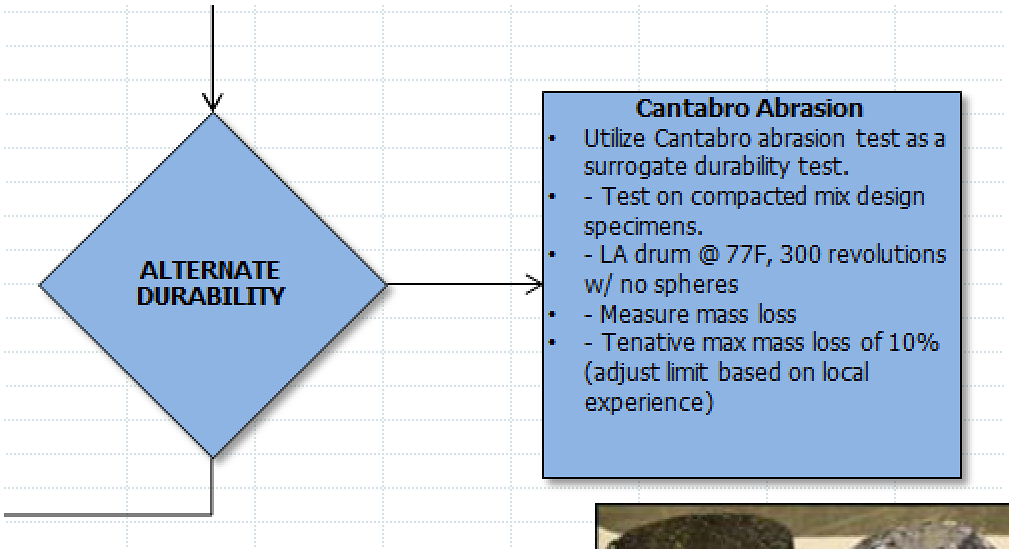
Minnesota Department of Transportation's Road Research Facility (MnROAD)
National Center for Asphalt Technologies (NCAT)

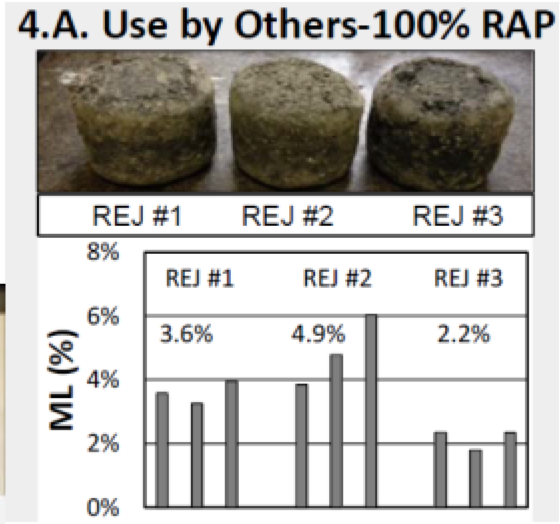
Quantifying the Benefits of Pavement Preservation
and
Development of Asphalt Cracking Performance Tests

2015 Track Research Cycle
- ~ 3 yr. cycle length

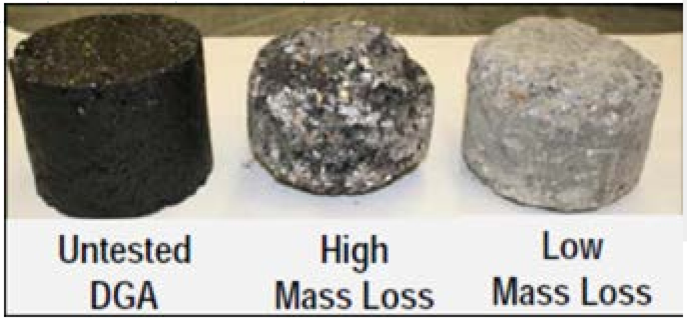
Optimized Mix Design Approach – Framework

- **Alternate Check Durability**
  - Cantabro test can provide a very quick, low cost durability measure



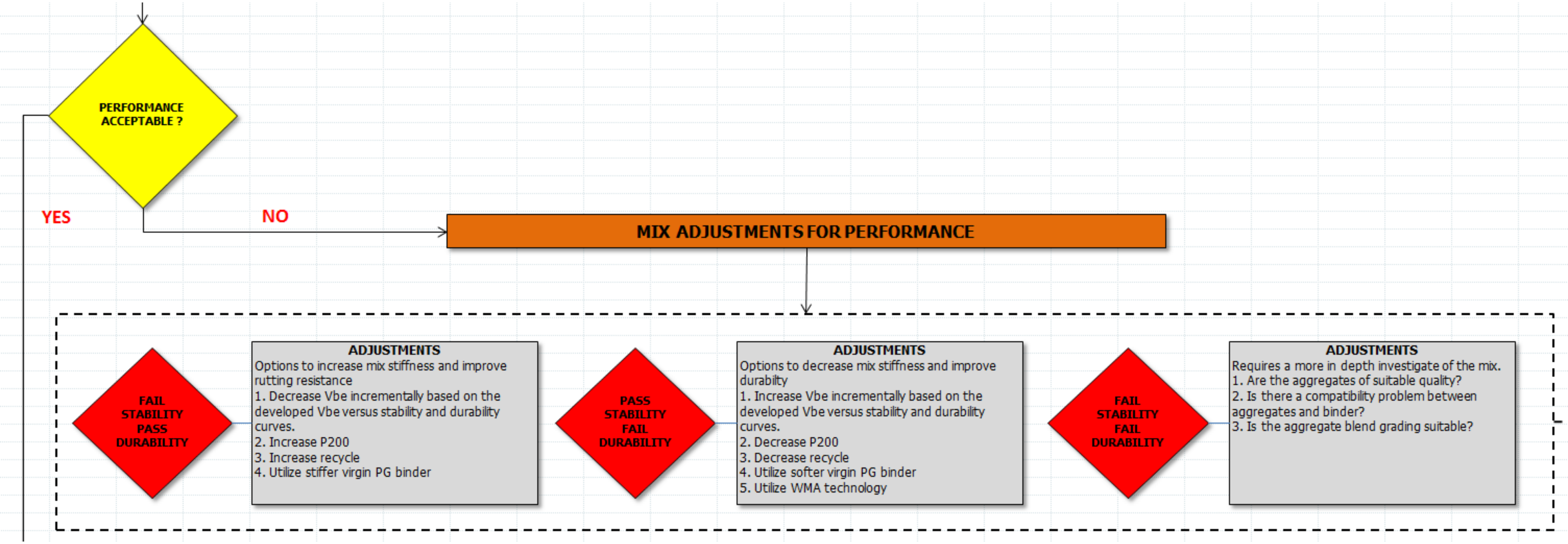


From: Issac Howard, SEAUPG 2014

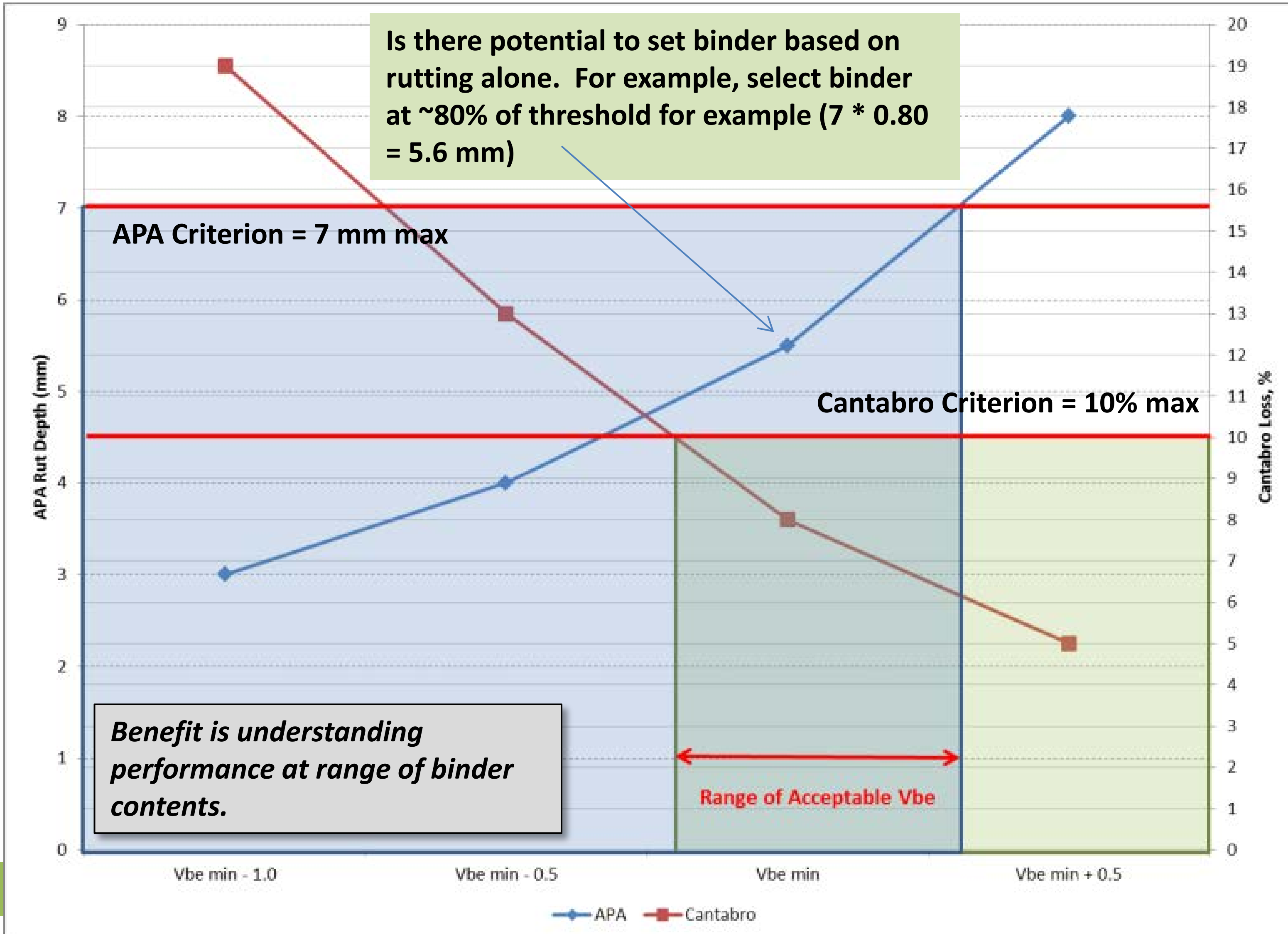


Optimized Mix Design Approach – Framework

- Evaluate Total Performance
  - Make necessary adjustments to improve stability and/or durability
  - If acceptable, proceed to economic analysis

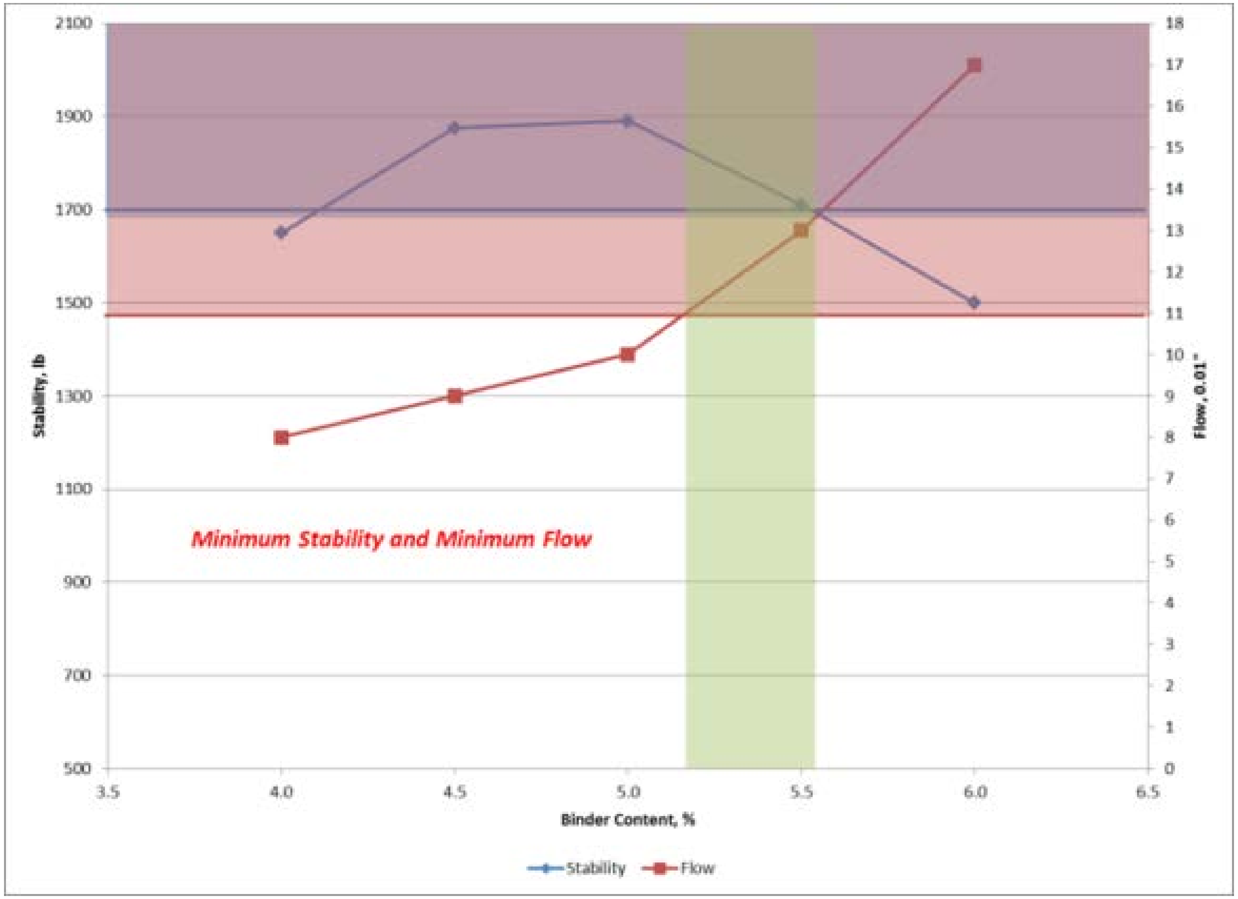


Design Performance Curves - Example



Other Possible Mix Evaluation Methods

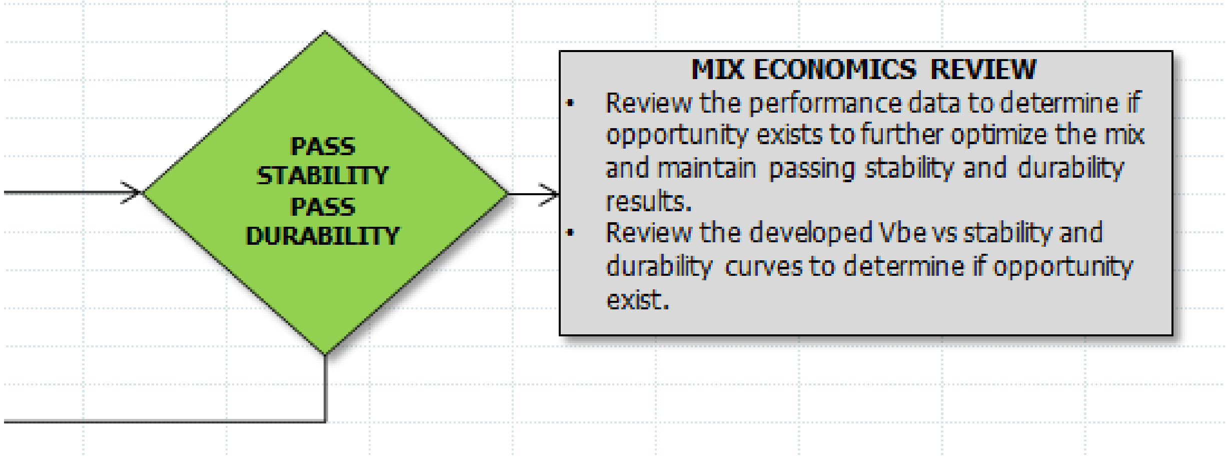
- Desired attributes (Design + QC)
  - Minimal time + effort, expense, specimen preparation
  - Maximum use, understanding, performance correlation
- **Marshall Stability and Flow**
  - Min stability and Min flow
- **Marshall Quotient or Stiffness (Stability/flow)**:
  - High values = stiff mixes
- **Indirect Tensile**
  - Strength (dry): High values = generally stiffer mixes
  - Failure strain: Low strains @ failure = generally stiffer mixes



Could the Old Become New Again?

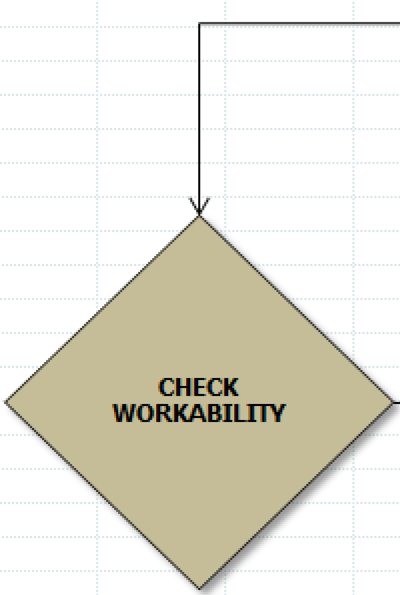
Optimized Mix Design Approach – Framework

- **Evaluate Mix Economics and Opportunity for Further Innovation**
  - Evaluate performance curves to make sure meaningful optimization opportunity is not lost.
  - Utilize obtained knowledge of the mix to maximize performance while minimizing cost



Optimized Mix Design Approach – Framework

- **Evaluate Mix Workability/Constructability**
  - Determine the relative compactability of the mix being designed and compare to a known standard.
  - Utilize Marshall hammer to simulate field rolling (i.e., constant applied stress similar to roller).



WORKABILITY EVALUATION

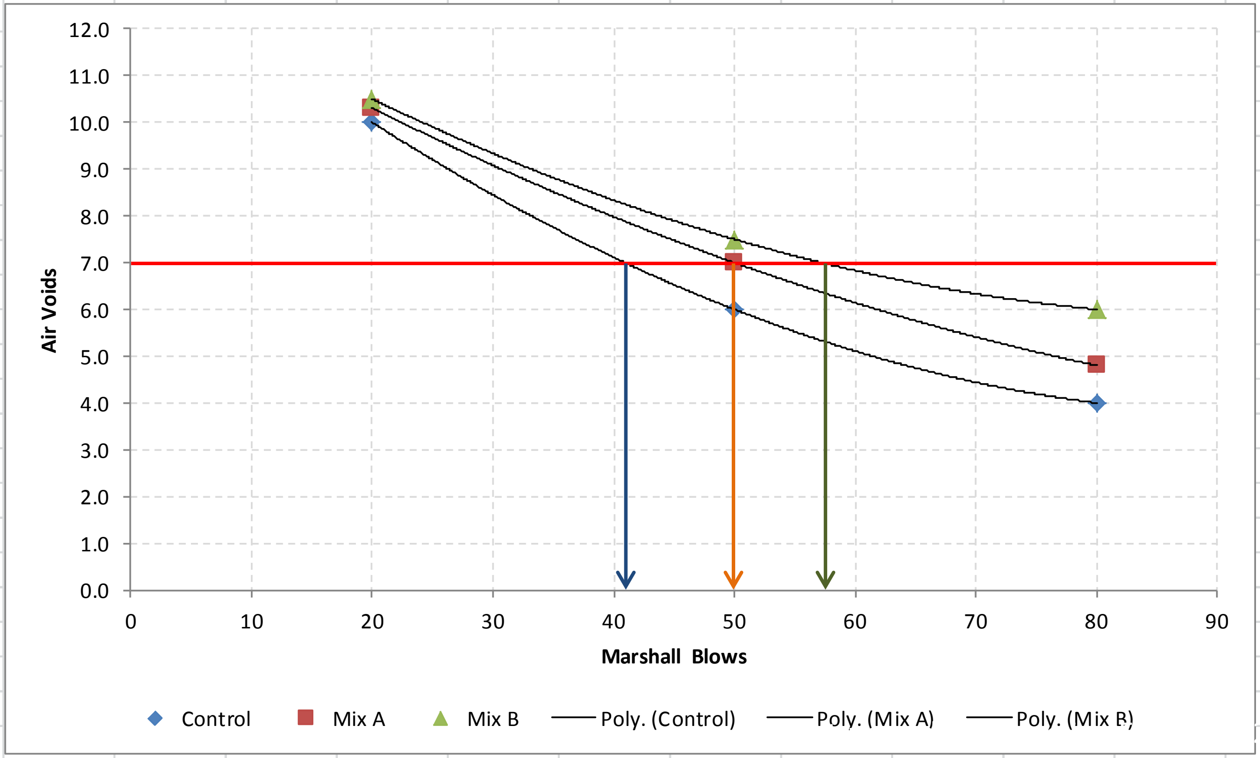
- Evaluate the relative compactability of mixes using one of two approaches.
- Marshall Compactability Index
- Compact mixes in Marshall mold at varying blows per one side
  - Three compaction levels to define the stiffness/blow curve
    - For example, 20, 50, and 80 blows
  - Measure heights of compacted specimens, calculate Gmb (based on mass/volume), calculate air voids
  - Develop compaction vs voids curve (workability curve)
    - Fit regression line to data
    - Conduct for standard or "control" type mixes as reference
    - Perform similar evaluation for mix(es) in question
  - Determine from the workability curve, the blows corresponding to the desired in place density of the mix(es). For example, if the specification requirement was 94% of Gmm, use 6% air voids.
  - Compare the Bd values for the control and the mixes in question
    - Divide the Bd for the mix being designed by the Bd value of the control to get an index value (Bdm/Bdc).

Workability - Example

- Compared to the control mix, Mix A and B would both be expected to be more difficult to compact with all factors being equal. Mix B would be the most difficult.
- Knowing the field compatibility of the control, guidance can be delivered to field personnel regarding the need for potential changes to the laydown operation.

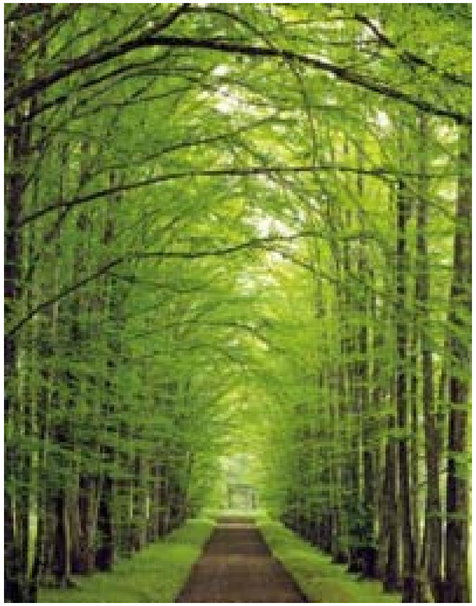
Compaction Workability Example

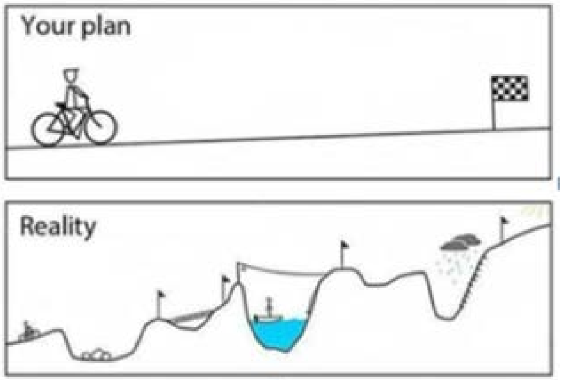
Blows	Air Voids		
	Control	Mix A	Mix B
20	10.0	10.3	10.5
50	6.0	7.0	7.5
80	4.0	4.8	6.0
Blows @ 7%	41	50	58
		1.22	**1.41**



The Path Forward

- Proof of concept testing is being conducted with selected Oldcastle companies
- Other evaluation/testing is welcomed
- Review results and adjust procedure accordingly
  - Continually adjust based on experience
- Must continue with theoretical research/modeling efforts, but not be afraid (or too proud) to utilize practical approaches to find solutions.
- **This is a long term effort with ups/downs, but we must start now.**





Thoughts and Questions?

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