Selection Of A Durable, Sustainable And Cost Effective Asphalt Mixture For Pavements In Oregon

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Outline

- Introduction
- Problem statement
- Objectives
- Methodology
- Strategies for Mix Design
- Results
- Major conclusions

Asphalt mixture?

Additional Additives

- **Warm Mix**
- **Latex**
- **Rubber**
- **Recycled Plastic**
- **Lime**
- **Fibers**

+

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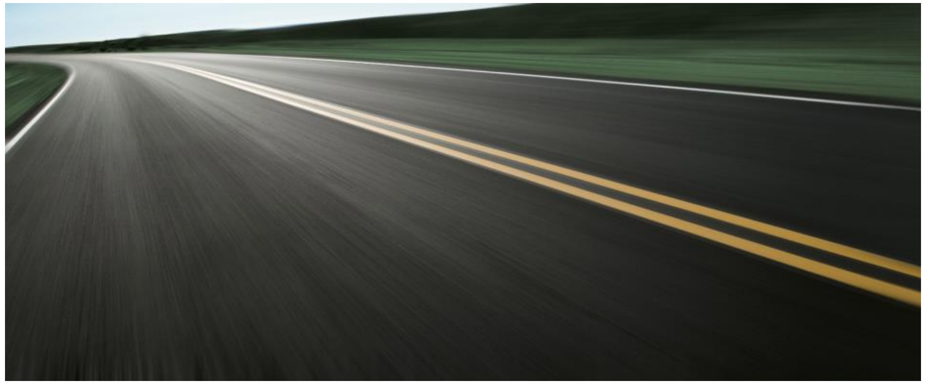
pavementinteractive.org

parkleasandsoil.com.au



https://www.pinterest.com/pin/671528994411571559

Asphalt Surfaced Pavement Distresses

Rutting

Low temperature cracking

Fatigue cracking

https://www.pavementinteractive.org, https://www.wolfpaving.com/blog/what-to-do-when-you-see-alligator-cracking-in-asphalt

Problem Statement

Ideal mix design

- ✔ Excellent performance
- ✔ Pavement longevity
- ✔ Environment

Factors affecting current Mix Design:

- Aggregate source and gradation,
- Asphalt source and grade,
- Air voids,
- Voids in mineral aggregate (VMA)
- Voids filled with asphalt (VFA)

Volumetric Properties


SHRP-A-407

The Superpave Mix Design Manual for New Construction and Overlays

Ronald J. Cominsky
University of Texas at Austin

With contributions by:

Gerald A. Huber
Heritage Research Group

Thomas W. Kennedy
University of Texas at Austin

Michael Anderson
The Asphalt Institute

shrp **Strategic Highway Research Program**
National Research Council
Washington, DC 1994

Existing analysis and design methods → empirical

- *Need for holistic evaluation and design of asphalt mixture based on performance*

- ✔ *Cracking*
- ✔ *Rutting*

Objectives

- ✔ Design three trial asphalt mixtures
- ✔ Evaluate the trial mixes for cracking and rutting performances
- ✔ Determine design binder content range for each mix using the balanced asphalt mix design method developed for Oregon
- ✔ Determine the cost and environmental impact of all three mixtures

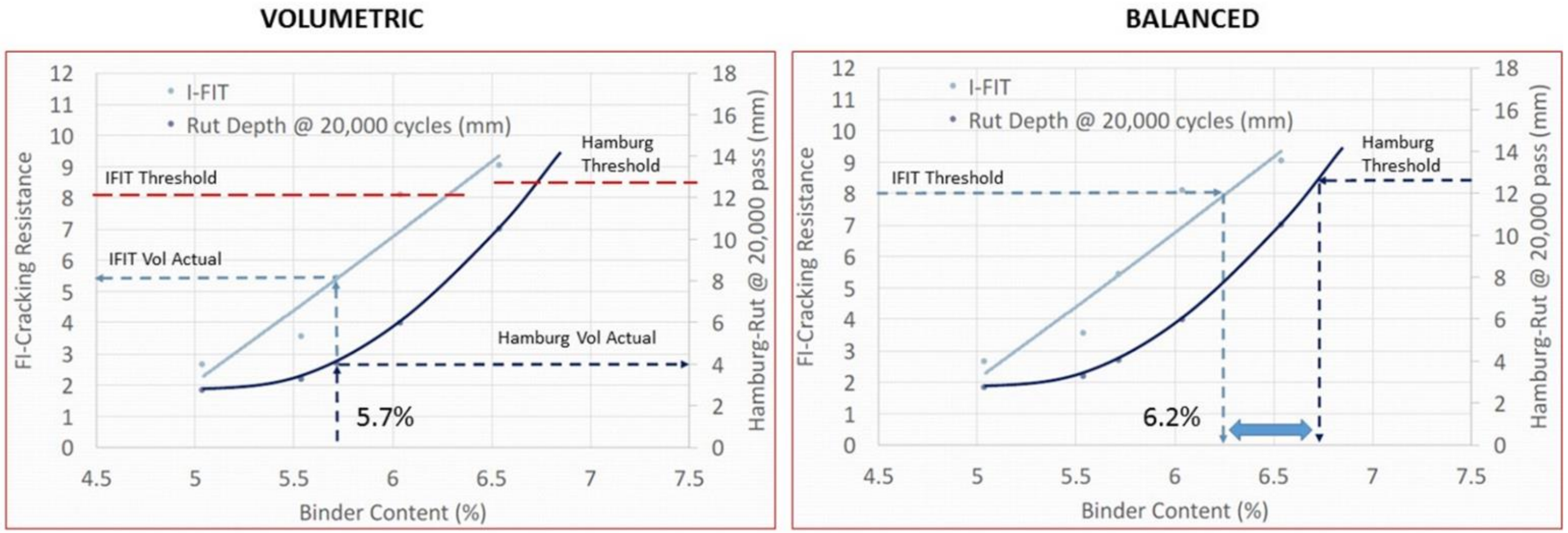
↓

- ✔ *Recommend the "best" asphalt mixture for the given conditions by considering the cost-effectiveness, sustainability and the long-term performance of the mixes*

Balanced Mix Design

"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".

Volumetric Mix Design vs Balanced Mix Design (Example)

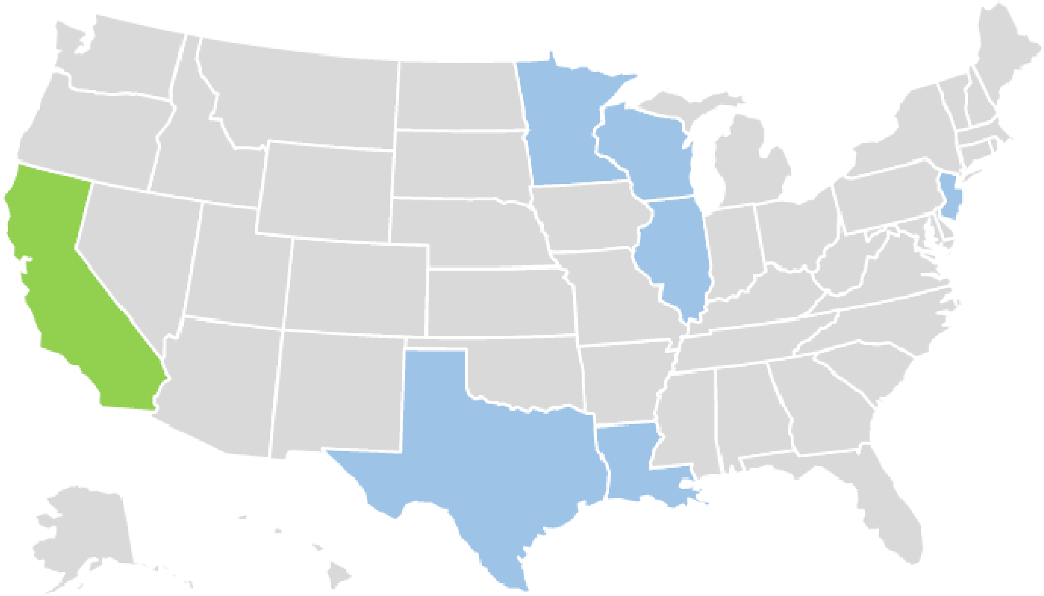


Note: Example for Illustration Purposes.

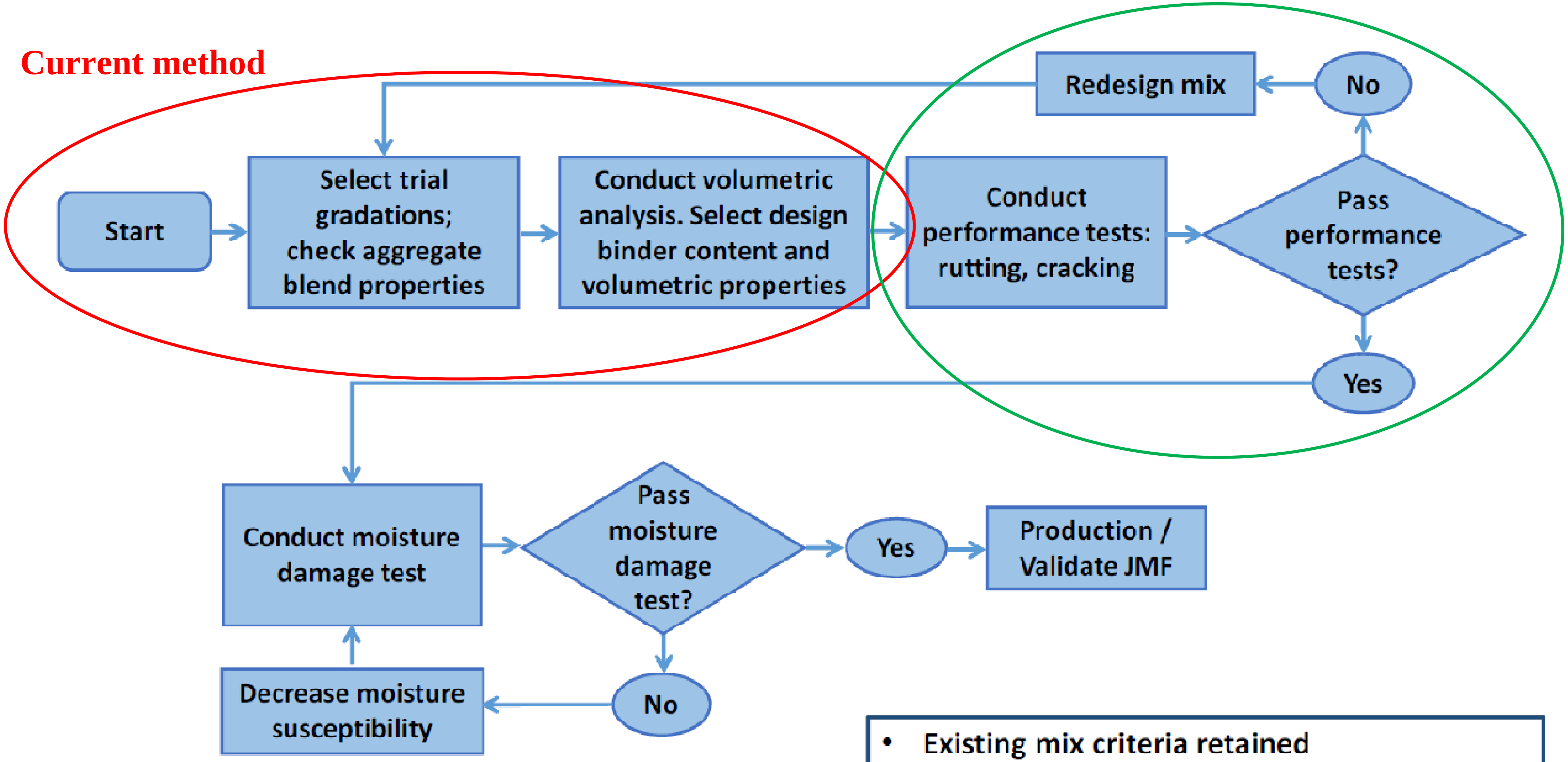
Source: NCAT Balanced Mix Design Training Course

Balanced Mix Design Approaches

1. Volumetric Design with Performance Verification
2. Performance-Modified Volumetric Mix Design
3. Performance Design



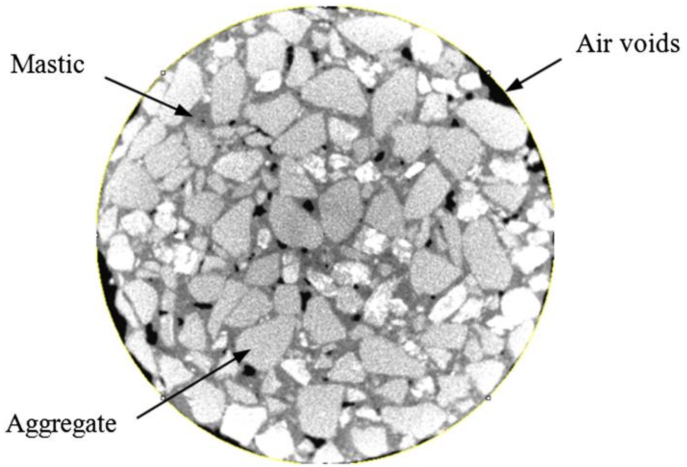
Approach 1 Volumetric Design with Performance Verification



- Existing mix criteria retained
- Criteria for rutting and cracking tests added

Strategies for Mix Design

Mix1. Density Effect



Source: Presti et al (2015)

Mix compacted to → 5% AV / 7% AV

30% RAP mixture

Mix2. High RAP content

Source: https://www.kwcornerstone.com/b/recycling-asphalt-pavement-for-your-cambridge-property--the-environmental-impact-of-green-paving

RAP content increased to 45%

Mix3. Warm-Mix Asphalt

Source: FHWA

Mix1: Density Effect

- Volumetric mix design with current process and Superpave 5 process i.e., mix designed at and compacted to 5% airvoid.

- Impact on stripping and permeability not investigated but Superpave 5 mix is expected to have higher cracking and rutting resistance.

Mix with 5% target airvoid (Superpave5)

Mix with 7% target airvoid (conventional)

Mix2: High RAP content

- Reduction in pavement life cycle costs, conserves natural resources, protects the environment
- Currently in Oregon, 20-30% Reclaimed Asphalt Pavement is commonly used in pavements.
- For this strategy, RAP content was increased to 45%

Mix3: Warm Mix Asphalt

- Evotherm® was used as a warm-mix additive
- The chemical additive dosage was calculated according to the following equation:

$$\%\,Adjusted\ Evotherm\ dosage = \frac{(\%\,Target\ Evotherm\ dosage) \times (\%\,Total\ binder)}{(\%\,Total\ binder\ -\ \%\,Binder\ from\ RAP)}$$

Mix Type	Mixing Temperature (°C)	Compaction Temperature (°C)
HMA (Mix1)	173	160
WMA (Mix3)	140	126

Experimental Plan and Production Mixture Information

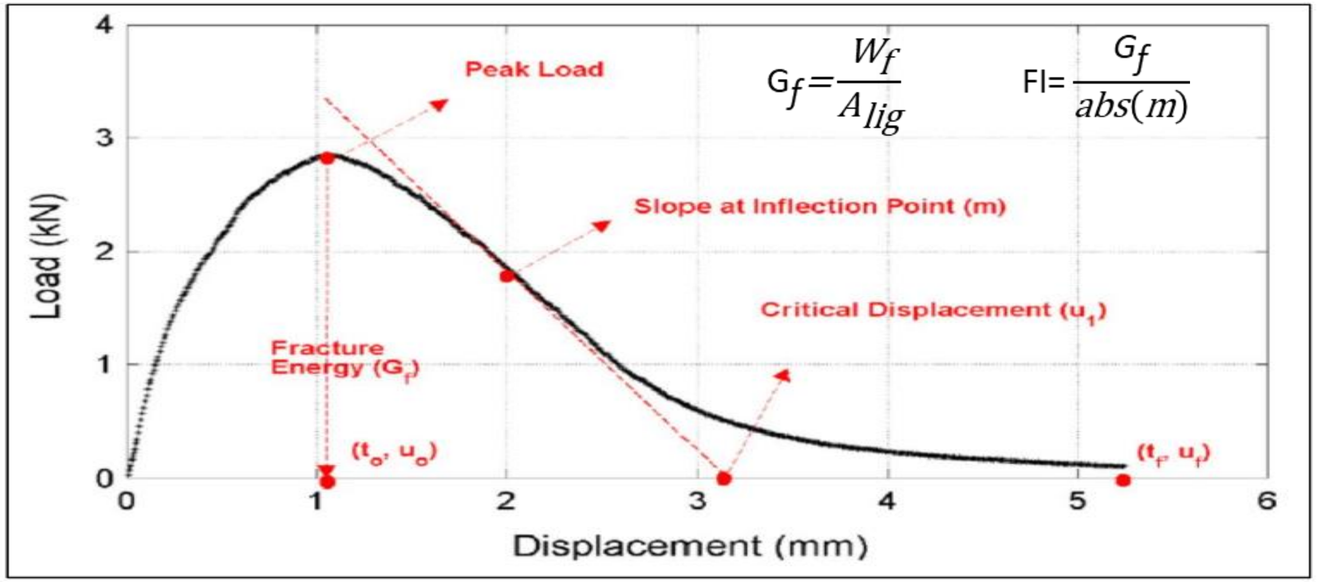
ID [a]	Binder Grade	RAP [b] (%)	AC_{RAP} (%)	AC [c] (%)	BR [d] (%)	P_{be} [e] (%)	P_{200}/P_{be} [f] Ratio	Addi.[g]	VMA[j]-VFA[k] %
Mix1_AV5	PG 70-22ER	30	5.02	5.6	26.9	4.63	1.4	1% Li[h]	16.1-69
Mix1_AV7		30		5.6	26.9	4.63	1.4	1% Li	16.1-69
Mix2		45		5.3	42.6	4.38	1.6	1% Li	15.6-68
Mix3		30		5.6	26.9	4.63	1.4	1% Li, 0.68% Evm[i]	16.1-69

[a] All mixtures had dense gradation and aggregates with a nominal maximum aggregate size of 12.5mm;
[b] RAP = Reclaimed asphalt pavement added by weight;
[c] AC = Total asphalt content by weight from volumetric design for 65 gyrations;
[d] BR = Binder replacement;
[e] P_{be} = Effective asphalt content present by weight in the total mix;
[f] P_{200}/P_{be} = Dust to binder ratio in the mix;
[g] Addi. = Additive; [h] Li = Lime; [i] Evm = Evotherm warm mix additive; [j] VMA = Voids in mineral aggregate;
[k] VFA = Voids filled with asphalt.

Semi Circular Bend Test

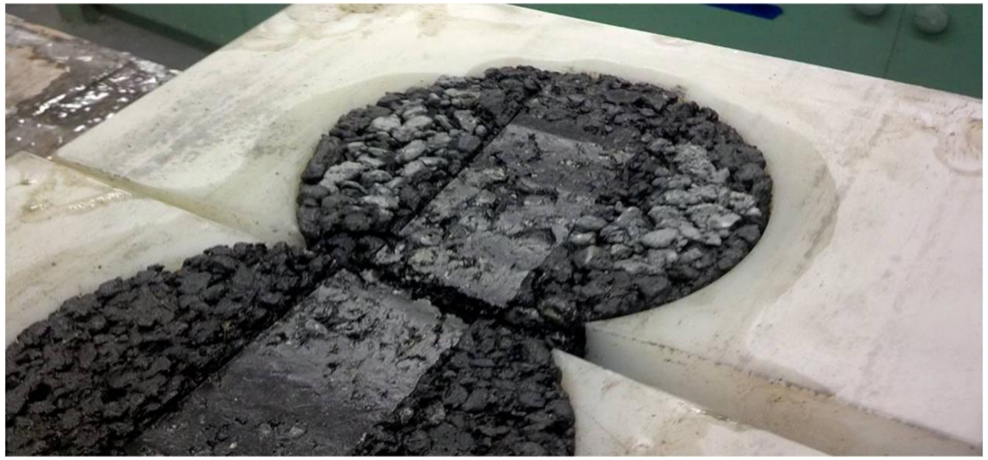
Semi Circular Bend Test – Oregon spec.

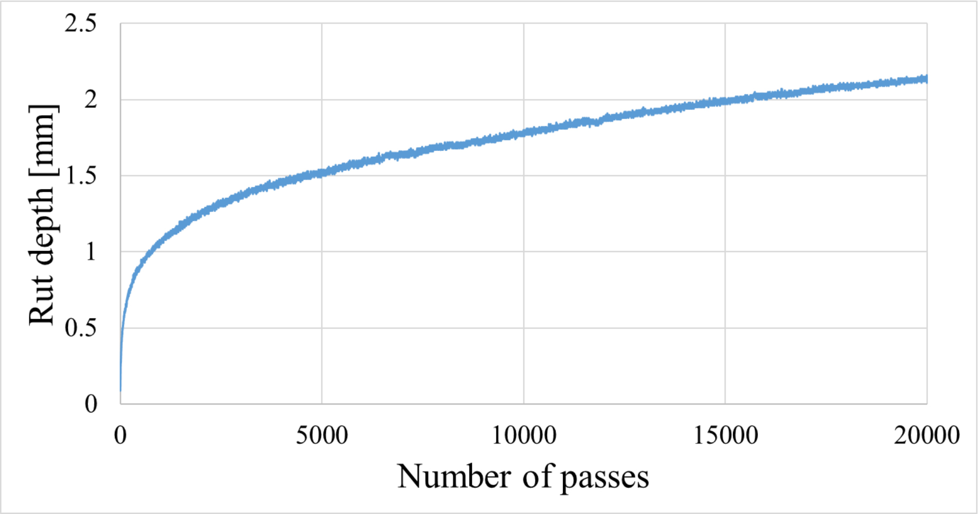
- Loading rate: **0.5 mm/min**
- Output parameters:
  - ✓ *Fracture energy (G_f)*
  - ✓ *Flexibility Index (FI)*



(Ozer et al. 2016)

Hamburg Wheel-Tracking Test (HWTT)





Experimental plan

Specimen Type [a]	Mix ID [b]	Test	Temperature (°C)	Asphalt Content (%)	Replicates	Total
LMLC	Mix1_AV5, Mix1_AV7, Mix3	SCB	25.0	OBC [c], - 0.5%, + 0.5%	4	36
		HWTT	50.0		4	36
	Mix2	SCB	25.0	OBC [c], + 0.5%, + 1%	4	12
		HWTT	50.0		4	12

a LMLC = Laboratory mixed, and laboratory compacted;
b Mix1_AV5 – Mix3 = LMLC samples from three trial mixes;
c OBC = Optimum binder content obtained from volumetric mix design.

Balanced Mix Design Thresholds for Oregon

Coleri et al. 2020

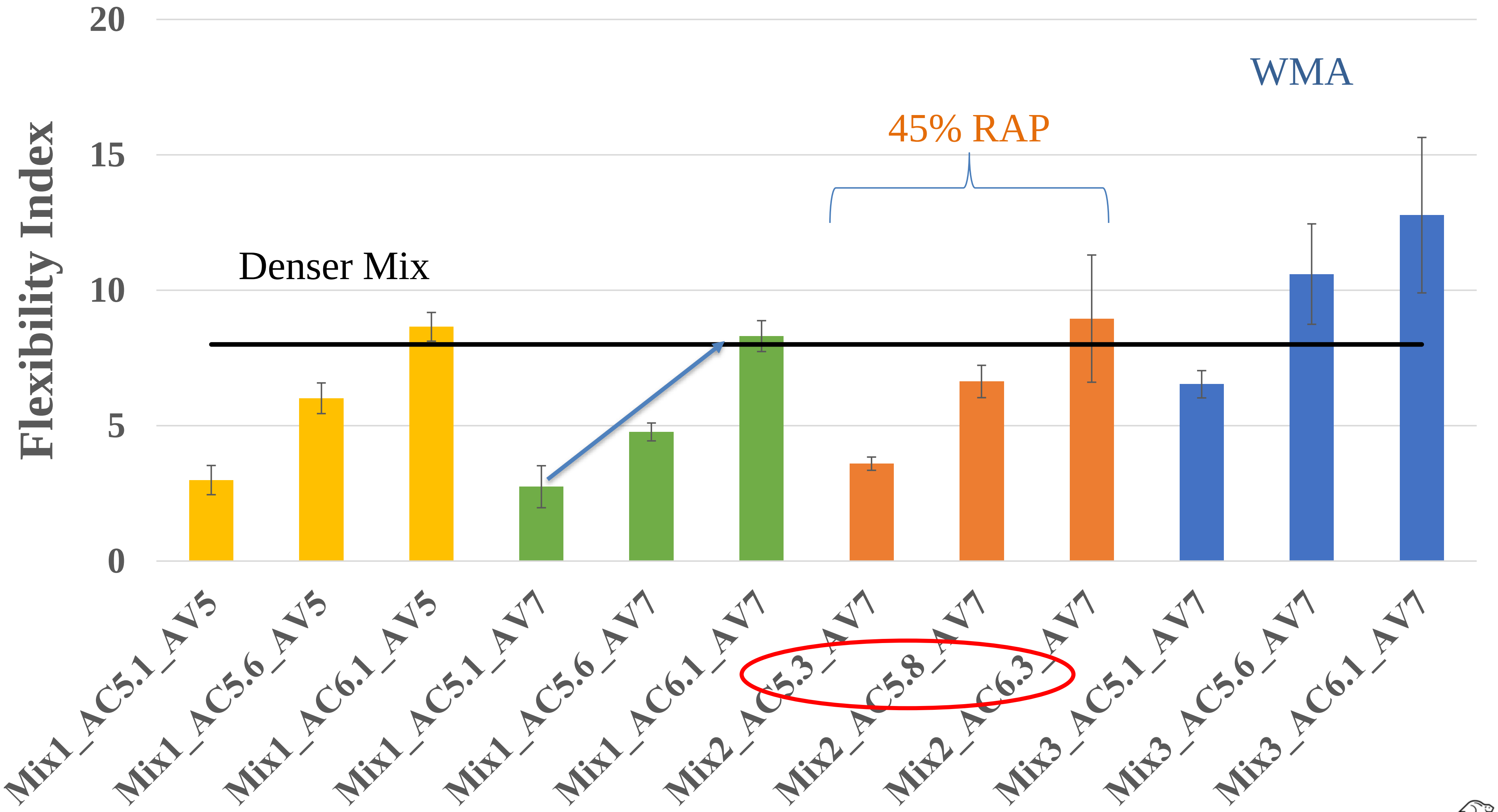
FI threshold of 6 was recommended for Level 3 mixes while the threshold for **Level 4 was selected as 8.**

RD threshold of 3mm was recommended for Level 3 mixes while the threshold for **Level 4 was selected as 2.5mm**

Competition traffic level: 20 year design ESAL of 7,500,000

Level 4 mixes are for high/heavy traffic volumes in Oregon (> 3 million ESALs for a 20-year design) – *ODOT Pavement Design Guide, 2019*

RESULTS – SCB Flexibility Index



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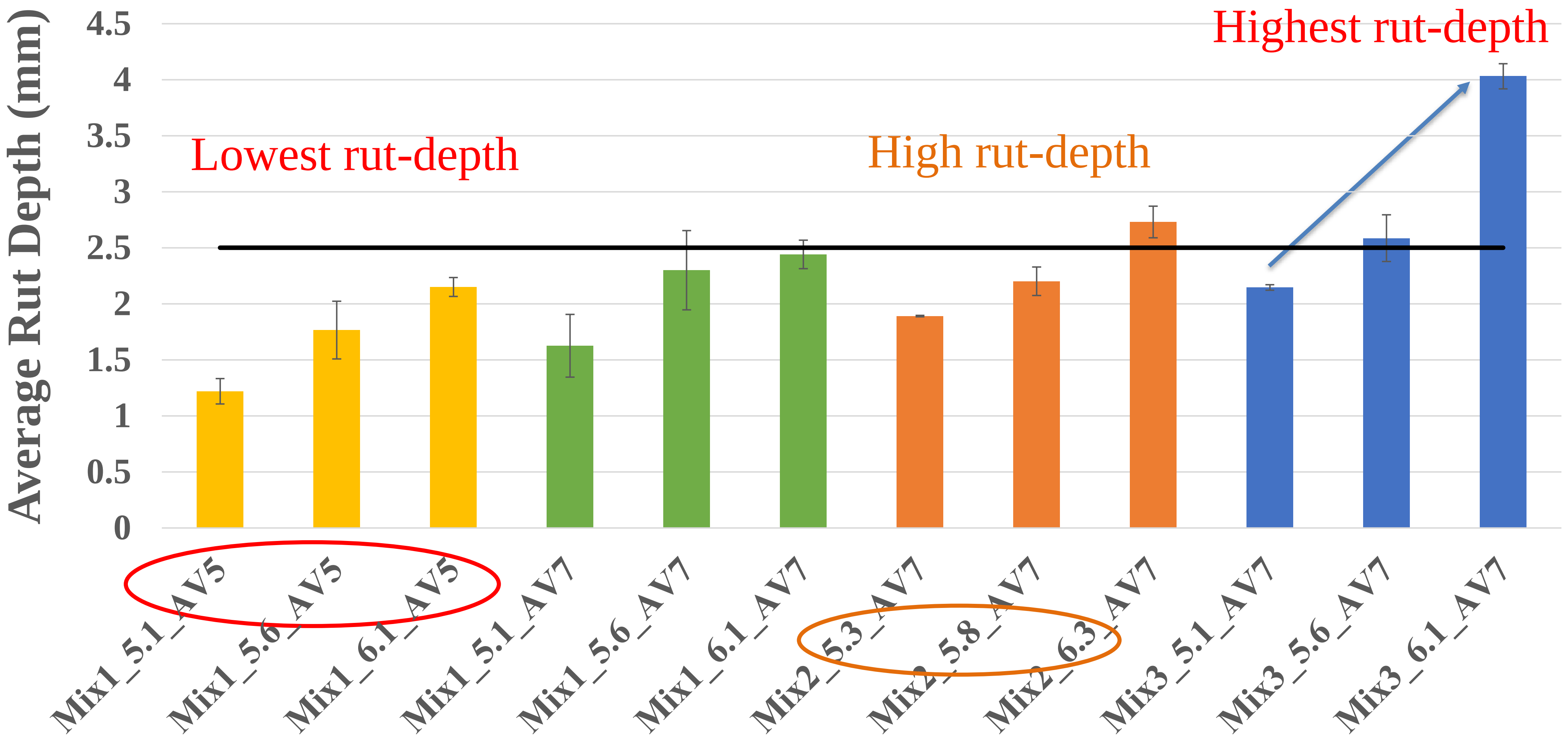
RESULTS – HWTT



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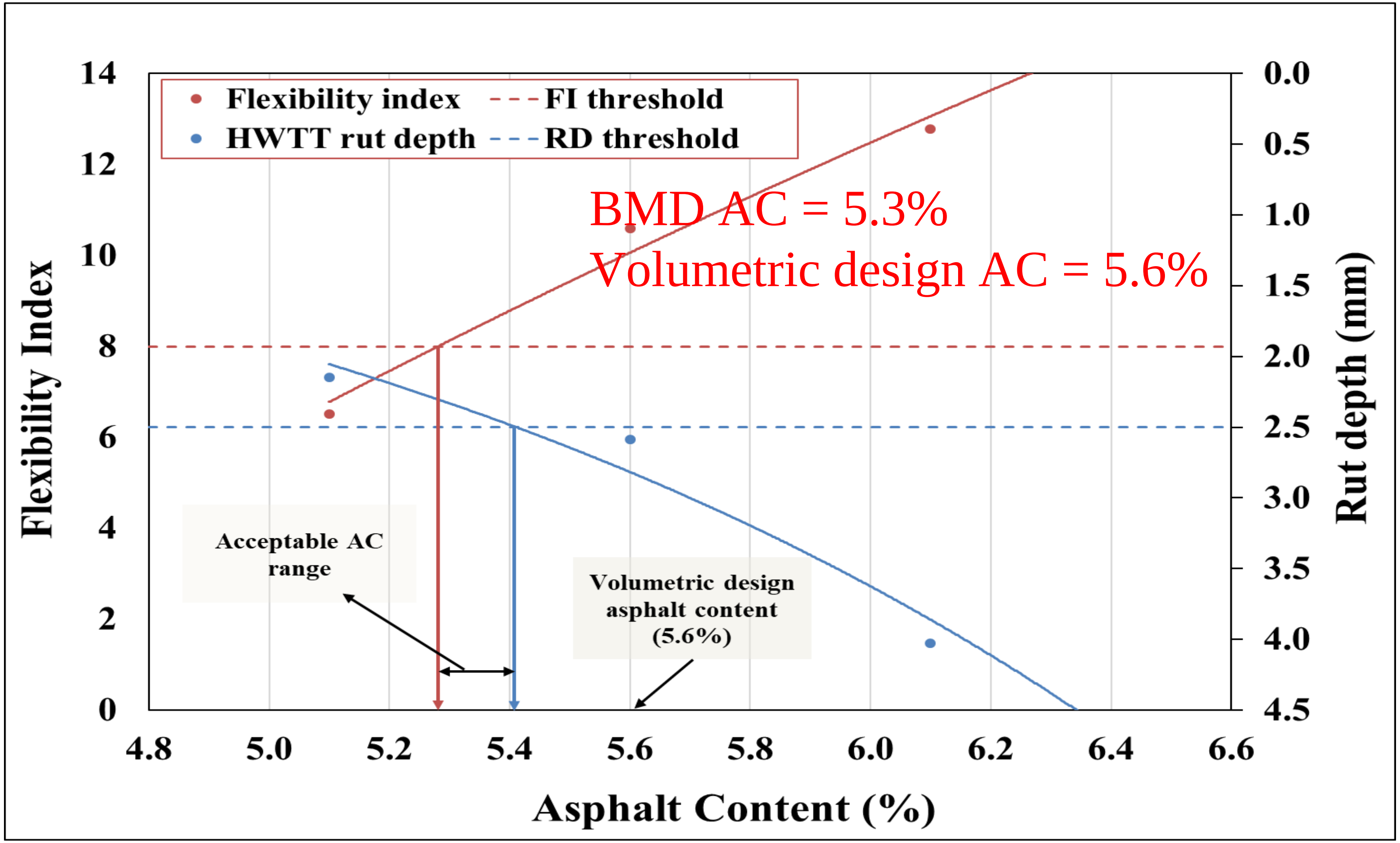
RESULTS – Balanced mix design process – Mixture 3 (WMA) results



RESULTS – Volumetric properties for the three mixes based on BMD design binder content

ID [a]	Binder Grade	RAP [b] (%)	AC_{RAP} (%)	AC [c] (%)	BR [d] (%)	P_{be} [e] (%)	P_{200}/P_{be} [f] Ratio	VMA[j]-VFA[k]%
Mix1_AV 5	PG 70-22ER	30	5.02	6.00	25.1	4.96	1.30	16.2-69
Mix1_AV 7		30		6.05	24.9	4.99	1.28	16.2-69
Mix2		45		6.10	37.0	5.04	1.27	15.4-68
Mix3		30		5.30	28.4	4.37	1.46	16.4-70

ODOT ACP Manual (2015)

	Limit
Air Voids	JMF Target ± 1.0%
VMA	12.5 - 17.0 (3/4" Mix) 13.5 - 17.0 (1/2" Mix) 14.5 - 17.0 (3/8" Mix)
VFA	65 - 75 (3/4" and 1/2" Mix in Level 3 and 4) 65 - 78 (3/4" and 1/2" Mix in Level 2) 70 - 80 (1/2" Mix in Level 1 and 3/8" Mix in Levels 1 - 4)
Passing No. 200/Pbe	0.8 - 1.6

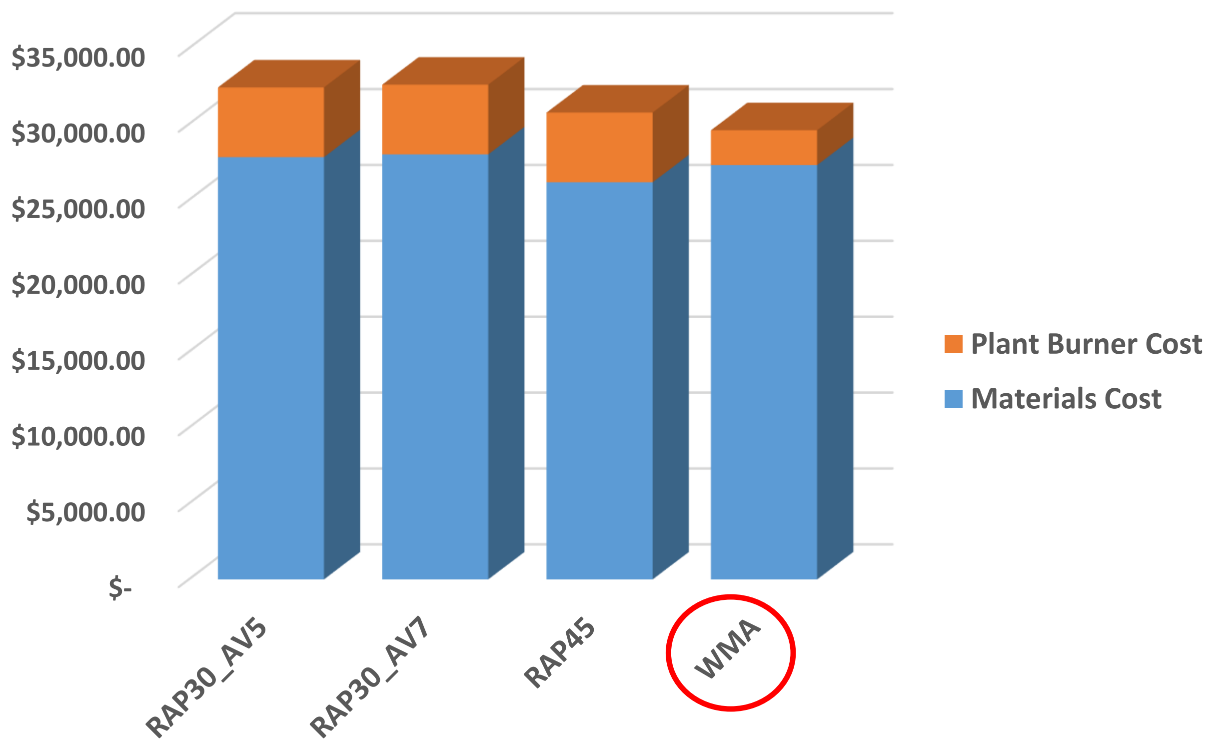
[a] All mixtures had dense gradation and aggregates with a nominal maximum aggregate size of 12.5mm;
[b] RAP = Reclaimed asphalt pavement added by weight;
[c] AC = Design BMD asphalt content added by weight;
[d] BR = Binder replacement;
[e] P_{be} = Effective asphalt content present by weight in the total mix;
[f] P_{200}/P_{be} = Dust to binder ratio in the mix;

RESULTS – Cost Calculation

	A	B	C	D	E
1	RAP & RAS Cost Calculator				
2	Mix Design 4				
3	Inputs:				
4	Product	Cost	Unit	Source	Type
5	Binder Type 4	$ 490.00	ton	ODOT	PG 70-22ER
6	RAP	$ 20.00	ton		
7	RAS	$ 40.00	ton		
8	Aggregate	$ 13.00	ton		
9					
10	Segment Property	Measure	Unit	Source	
11	Geometry	Straight	-	Assumption	
12	Length	1.0	mi	Assumption	
13	Lane Width	12.0	ft	Assumption	
14	Number of Lanes	1.0	each	Assumption	
15	Compacted Layer Thickness	2.0	in	Assumption	
16					
17	Mix Property	Measure	Unit	Source	
18	Compacted Density	145.0	lb/ft^3	NAPA website	
19	Target Binder Content	6.0%	by weight	Estimate	
20	RAP Content	30.0%	by weight	Estimate	
21	RAS Content	0.0%	by weight	Estimate	
22	Aggregate Content	64%	by weight	Calculation	
23	Binder Content (RAP material)	5.0%	by weight	Estimate	
24	Binder Content (RAS material)	0.0%	by weight	Estimate	
25	Virgin Binder Added	4.5%	by weight	Calculation	
26					
27	Outputs:	Measure	Unit		
28	Section Volume	10560	ft^3 (all lanes)		
29	Section Tonneage	765.6	tons (all lanes)		
30	Mix Cost	$ 27,844.87	segment		

<u>Cost of materials from previous years production:</u>

- RAP: $20/ton
- Aggregate: $13/ton
- PG70-22ER binder: $490/ton
- Evotherm P25: $70/ton



RESULTS – Life Cycle Cost Analysis

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

Where:

C_t = estimated agency costs at year t,

r = interest rate, and

T = number of time periods.

NPVs for all the mixes – Without burner fuel consumption cost

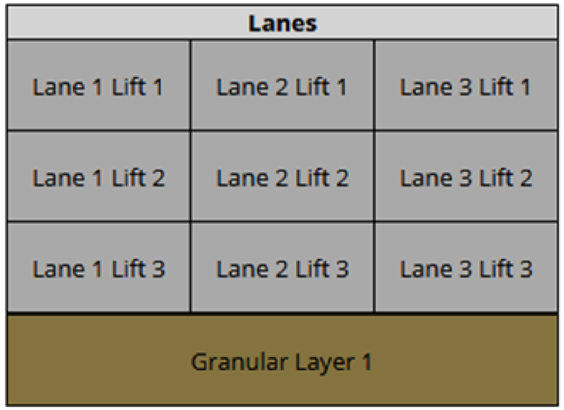
S. No.	Mix ID	Initial cost ($)	NPV-1 ($)	NPV-2 ($)	NPV ($)
1.	Mix1_AV5	27,823	12,698	5,795	46,316
2.	Mix1_AV7	28,005	12,781	5,833	46,619
3.	Mix2	26,167	11,942	5,450	43,560
4.	Mix3	27,299	12,459	5,686	45,444

NPVs for all the mixes – With burner fuel consumption cost

S. No.	Mix ID	Initial cost ($)	NPV-1 ($)	NPV-2 ($)	NPV ($)
1.	Mix1_AV5	32,416	14,794	6,752	53,962
2.	Mix1_AV7	32,599	14,878	6,790	54,267
3.	Mix2	30,761	14,039	6,407	51,207
4.	Mix3	29,597	13,508	6,165	49,269

METHODOLOGY – Life Cycle Assessment (Pavement LCA)

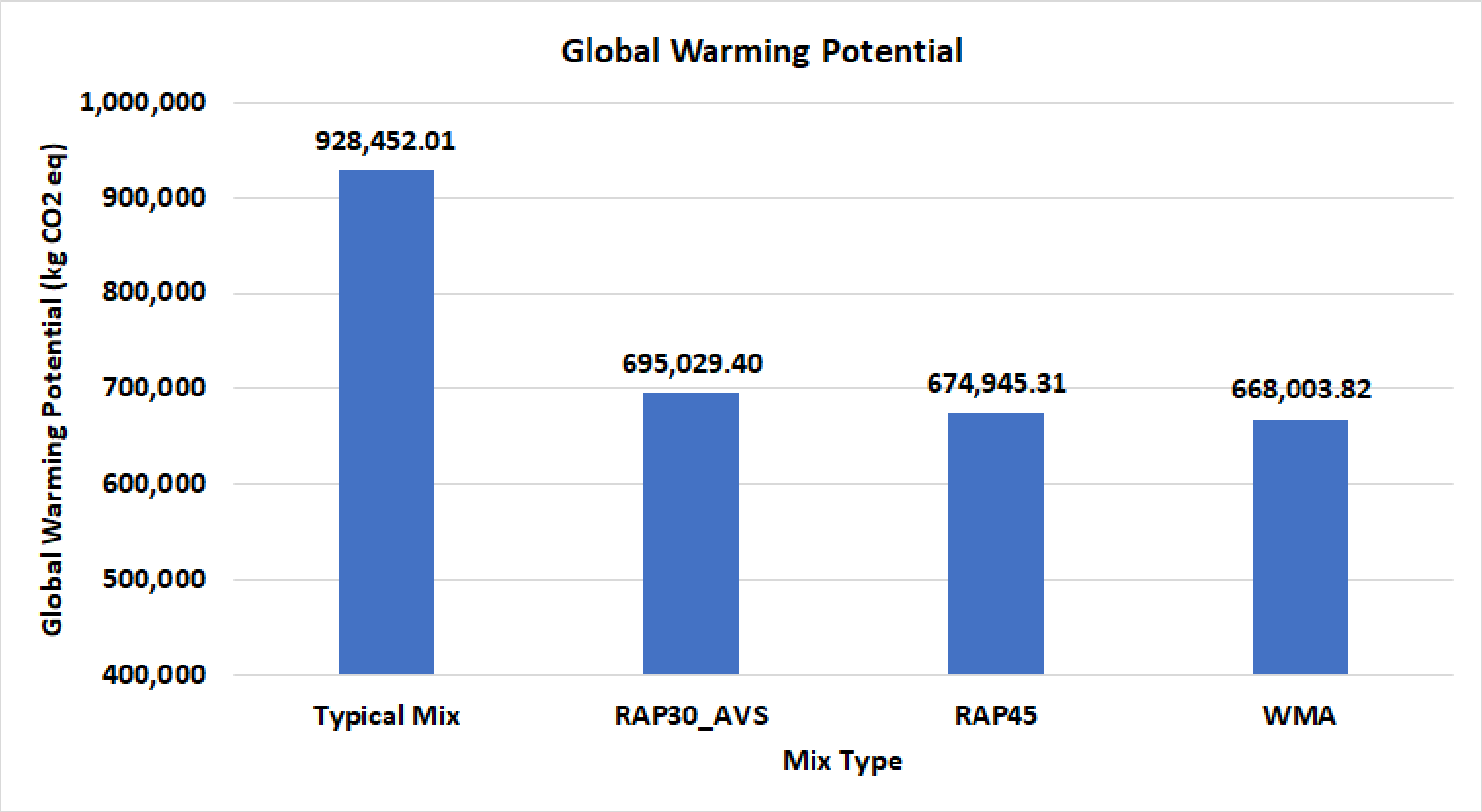
- Define pavement geometry and material inputs (binder content, binder type, WMA/HMA, etc.)
- Define rehabilitation schedule as maintenance every 20 years until the 60 year lifespan has been reached
- Run software and export global warming markers to excel



Activity Timing		
Year After Initial Construction	Expected Lifespan [Years]	Activity Type
20	20	Asphalt Milling
20	20	Asphalt Paving

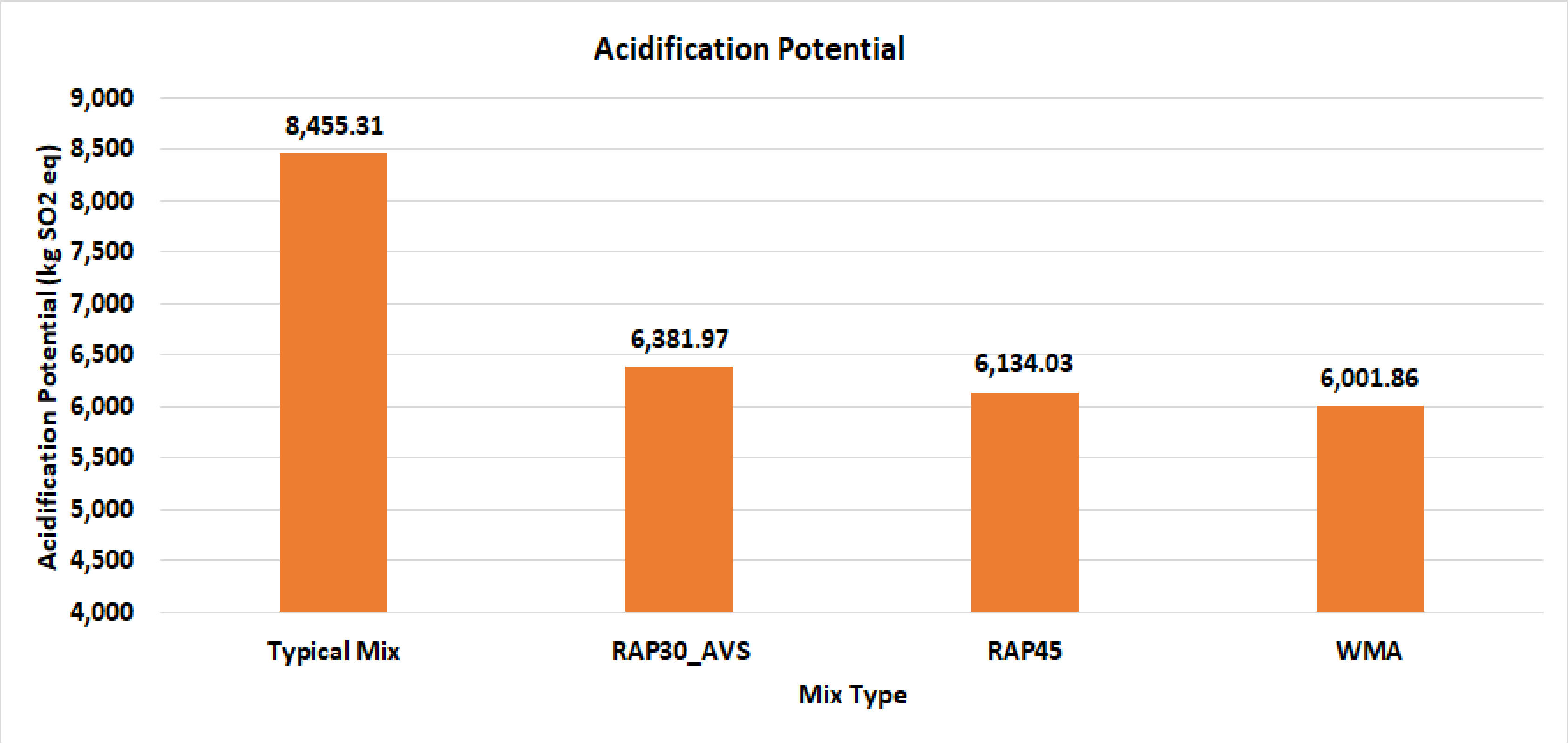
Model:		B3-R0-BC6		
Name	Unit	Materials and Equipment	Transport	Total
Global Warming Potential	kg CO2 eq	469,955.33	49818.53946	519773.8722
Acidification Potential	kg SO2 eq	4,077.53	502.5220314	4580.056696
HH Particulate	kg PM2.5 eq	247.69	26.1782047	273.8706779
Eutrophication Potential	kg N eq	173.58	31.19910521	204.7762385
Ozone Depletion Potential	kg CFC-11 eq	0.00	1.75653E-06	7.08015E-05
Smog Potential	kg O3 eq	42,615.98	15933.83337	58549.81465
Total Primary Energy	MJ	30,450,605.29	722007.2163	31172612.51
Non-Renewable Energy	MJ	29,909,129.90	721703.0524	30630832.96
Fossil Fuel Consumption	MJ	29,867,573.70	720569.7824	30588143.48

RESULTS – Life Cycle Assessment (Pavement LCA)



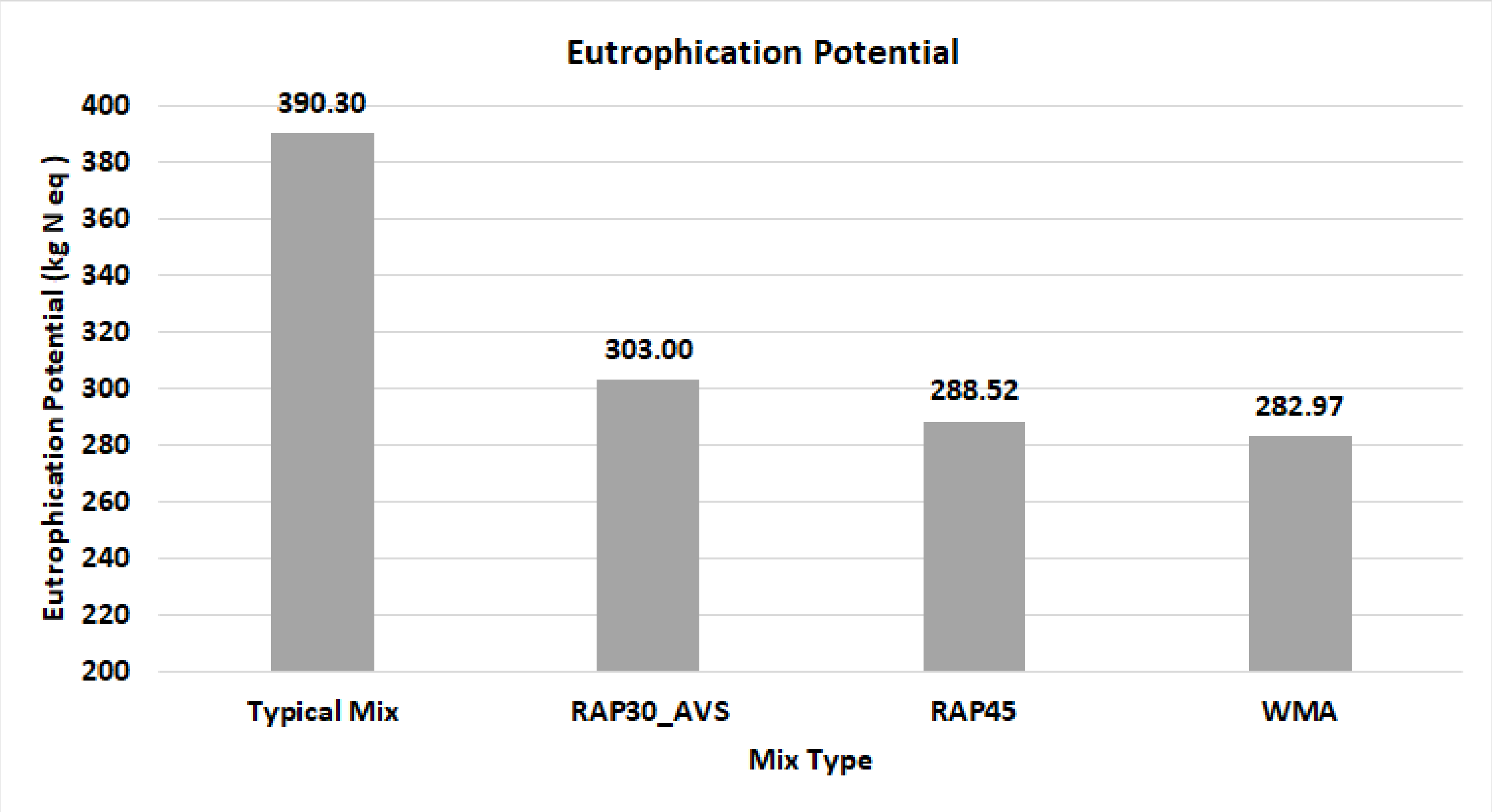
Name	Unit	Typical Mix	RAP30_AVS	RAP45	WMA
Global Warming Potential	kg CO2 eq	928,452.01	695,029.40	674,945.31	668,003.82

RESULTS – Life Cycle Assessment (Pavement LCA)



Name	Unit	Typical Mix	RAP30_AVS	RAP45	WMA
Acidification Potential	kg SO2 eq	8,455.31	6,381.97	6,134.03	6,001.86

RESULTS – Life Cycle Assessment (Pavement LCA)



Name	Unit	Typical Mix	RAP30_AVS	RAP45	WMA
Eutrophication Potential	kg N eq	390.30	303.00	288.52	282.97

Major Conclusions

- Mix3 has cracking resistances significantly higher than all other mixtures;
- It is possible that Mix 3 with warm-mix additives can have better “compactibility”;
- The most cost-effective mix is the warm mix asphalt (Mix 3) considering the reduced production temperature;
- Mix 3 (warm-mix) is also the most environmentally friendly mix with lower expected GWP, EP, and AP values for a 60 year analysis period;
- Based on the balanced mix design plots for the four mixes, the required asphalt content for Mix1_AV5, Mix1_AV7, Mix2 and Mix3 are 6.00%, 6.05%, 6.10% and 5.30%.

The mixture with warm-mix additives (Mix 3) is selected as the best asphalt mixture with lowest cost and lowest environmental impact.

Oregon State University

Thank You

GO BEAVS!

Beavers