Percent within Limits (PWL) and Balanced Mix Design (BMD):

An Update on WisDOT's Current Practice and Future Plans

WAPA Annual Conference

November 28-29, 2023

Dan Kopacz, PE

Ali Arabzadeh, PhD, PE

Bureau of Technical Services, WisDOT

PWL:

An Update on WisDOT's Current Practice and Future Plans

Dan Kopacz, PE

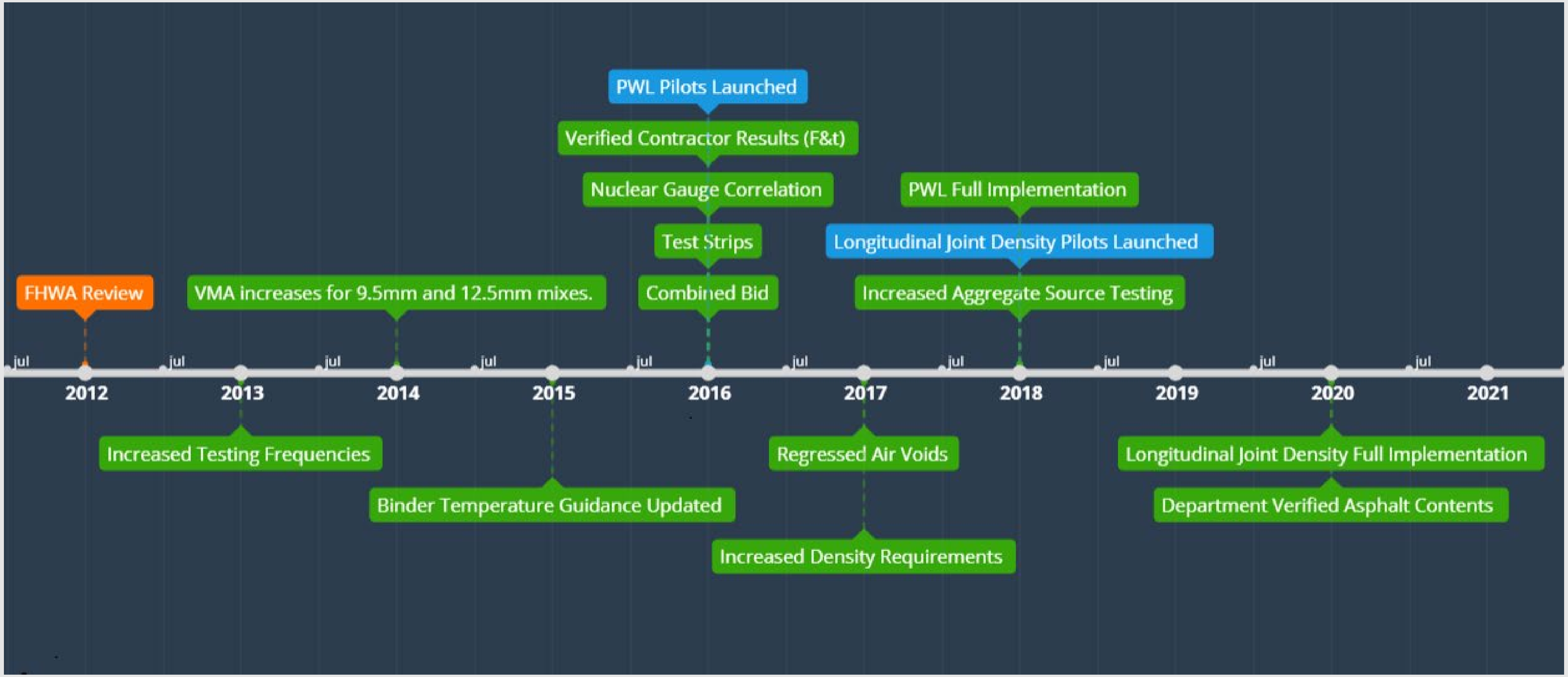
PWL Updates

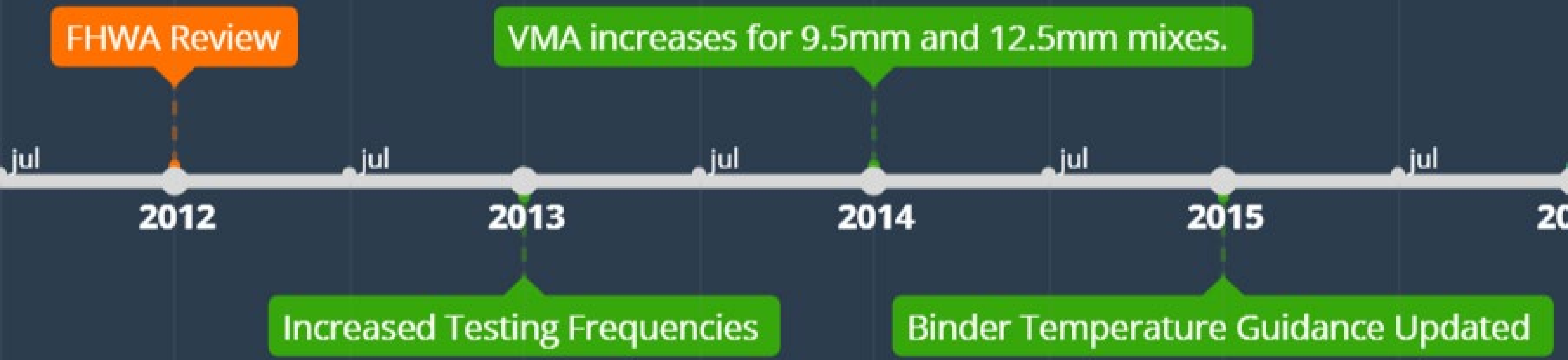
- History of PWL
- 2022 PWL summary data
- Where are we headed?

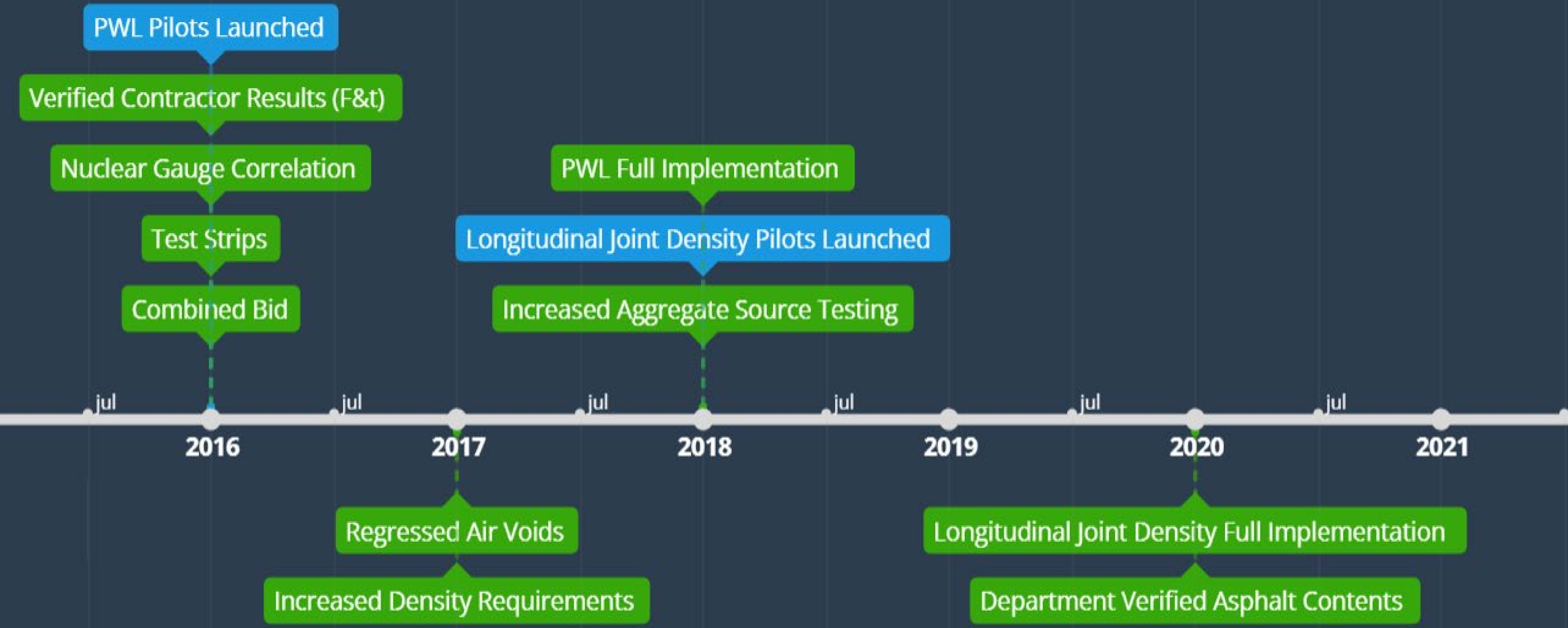
Quality Assurance Goals

- Remain FHWA Compliant
  - Code of Federal Regulations (CFR)
- Verify Contractor Data
  - F&t is used to verify contractor data
- Increase Consistency Near the Target
  - Percent Within Limits (PWL)
- Ensure Adequate Performance
  - Set appropriate specification limits

Where we were

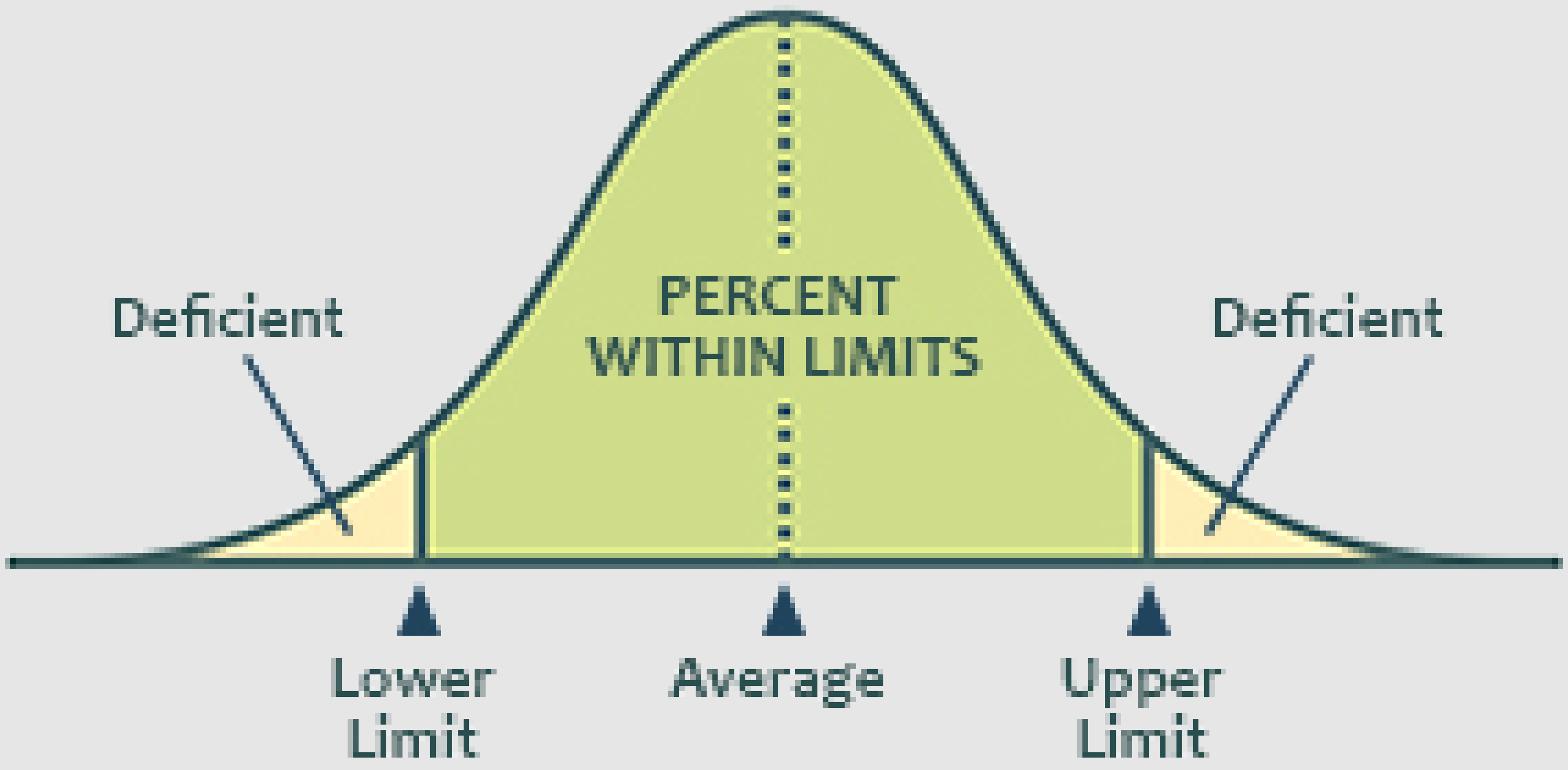



FHWA Review
VMA increases for 9.5mm and 12.5mm mixes.
jul
2012
jul
2013
jul
2014
jul
2015
jul
Increased Testing Frequencies
Binder Temperature Guidance Updated

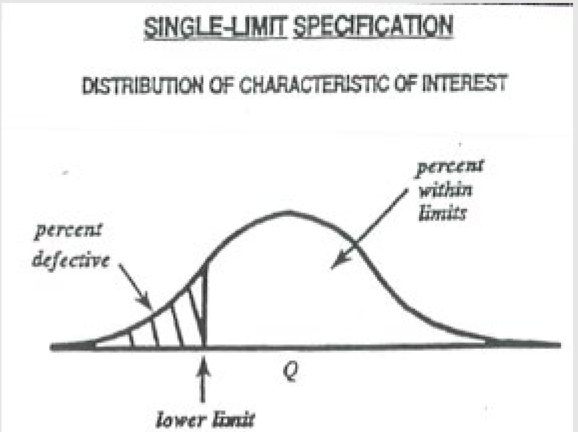


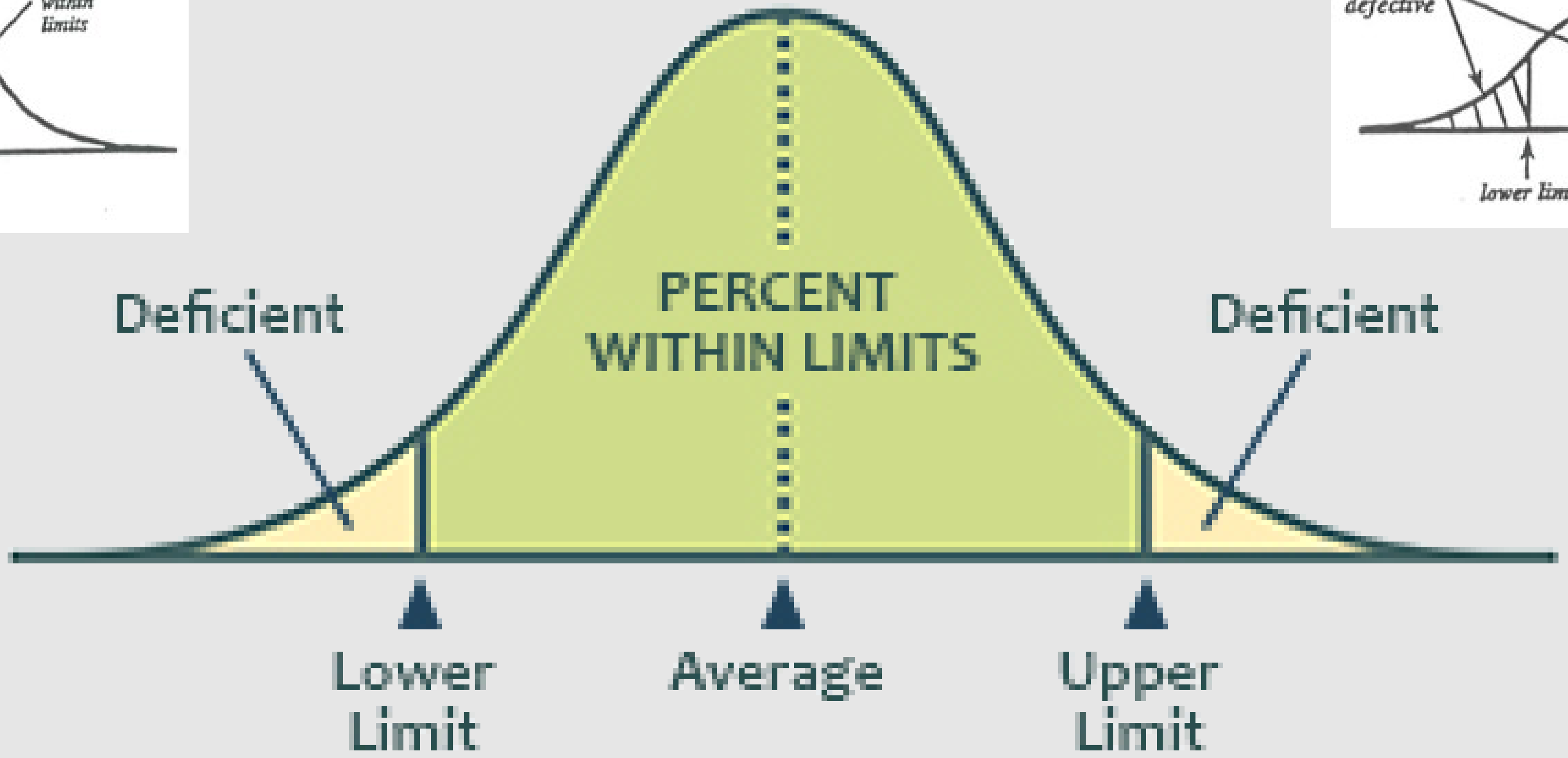
PWL Pilots Launched
Verified Contractor Results (F&t)
Nuclear Gauge Correlation
Test Strips
Combined Bid
PWL Full Implementation
Longitudinal Joint Density Pilots Launched
Increased Aggregate Source Testing
jul
2016
jul
2017
jul
2018
jul
2019
jul
2020
jul
2021
Regressed Air Voids
Increased Density Requirements
Longitudinal Joint Density Full Implementation
Department Verified Asphalt Contents

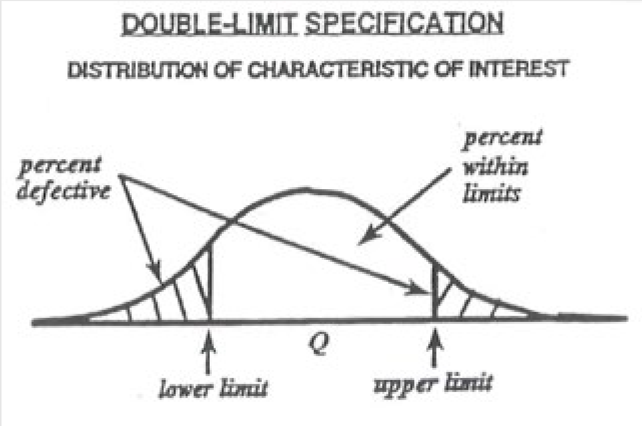
Percent Within Limits Analysis and Performance



Percent Within Limits Project Data







Background

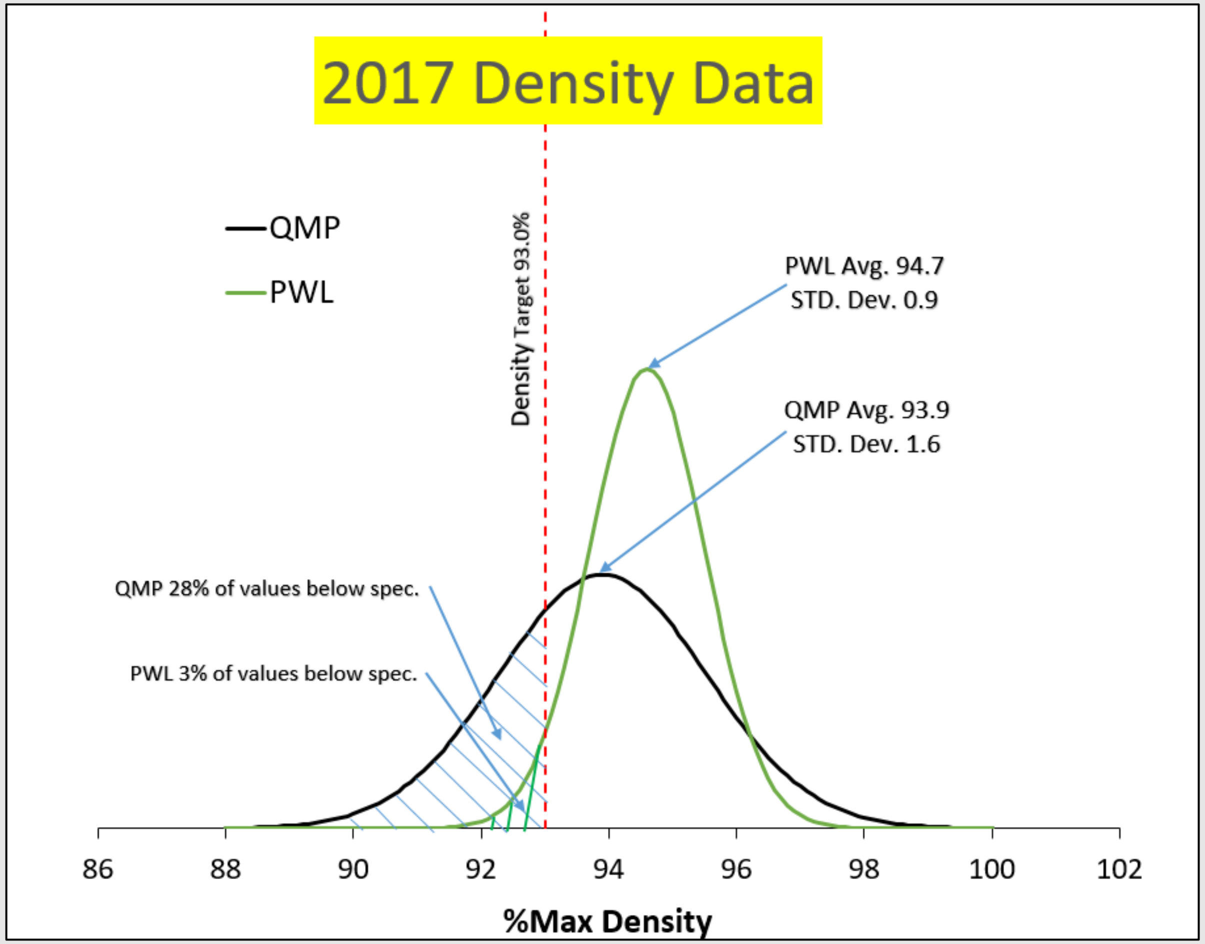
- A PWL value is calculated using lower limits for density (usually 93%) and lower and upper limits (2.0 and 4.3 respectively) for Air Voids.
- The PWL value is used in a pay equation to determine the Pay Factor (PF).
- Incentives and disincentives are calculated using $65/ton with the ability to get up to 4% in incentives (PF = 104).
  - PF > 100: Incentive
  - PF = 100: No incentive or disincentive
  - PF < 100: Disincentive
  - PF = 50: Contract unit price is used instead of $65/ton and paid at 50% or remove and replace.
  - Max possible incentive per ton is $2.60 ($65/ton * 0.04) or $1.30 each for density and air voids.

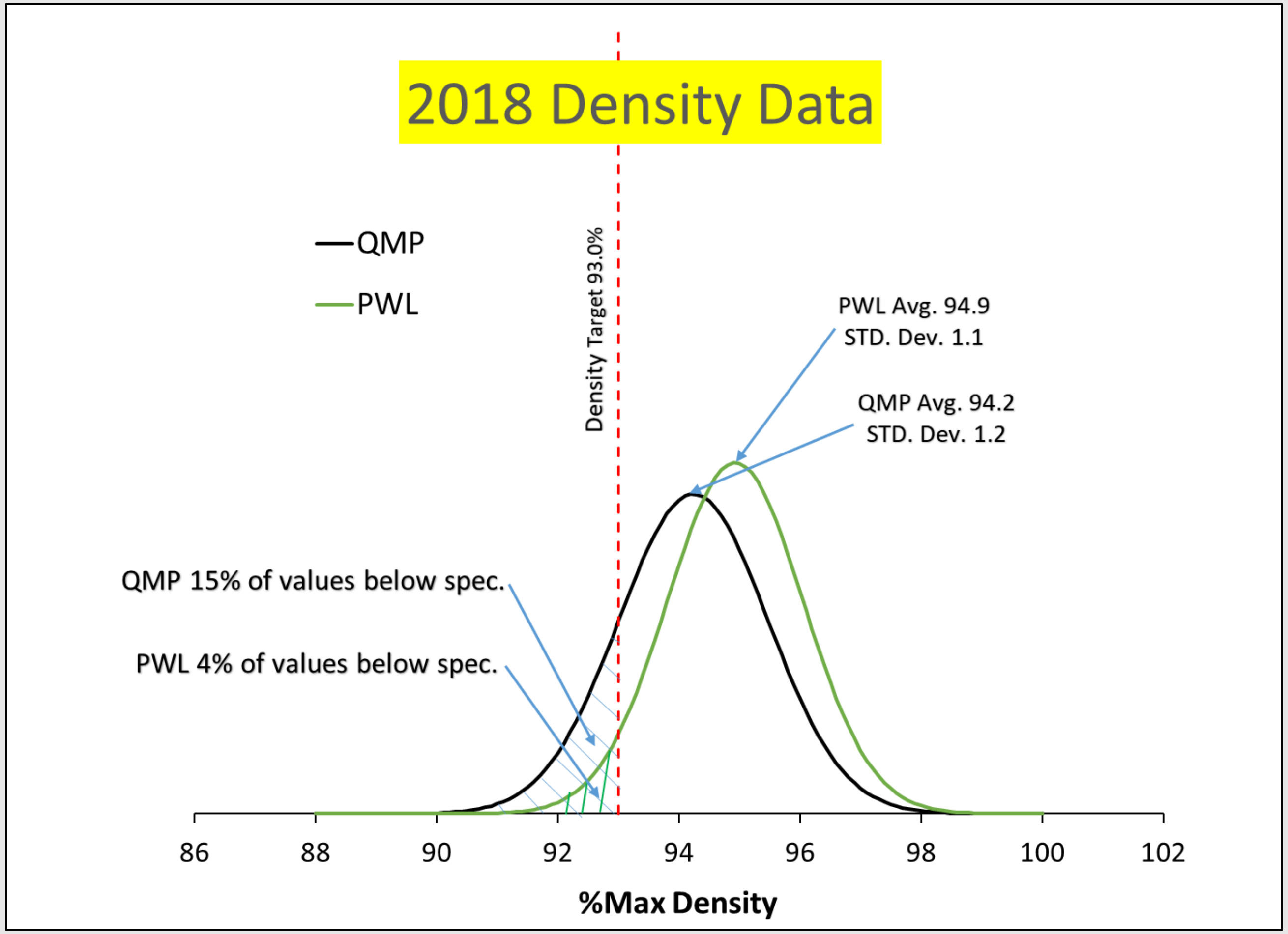
What Does It All Mean?

- Each of the improvements to the specification over the last decade have been instrumental in building better asphalt pavements.
  - Increased density = longer lasting pavements.
  - Additional asphalt = reduced cracking and aging.
  - PWL = more consistent, quality material.
  - Joint density testing = better performing joints.

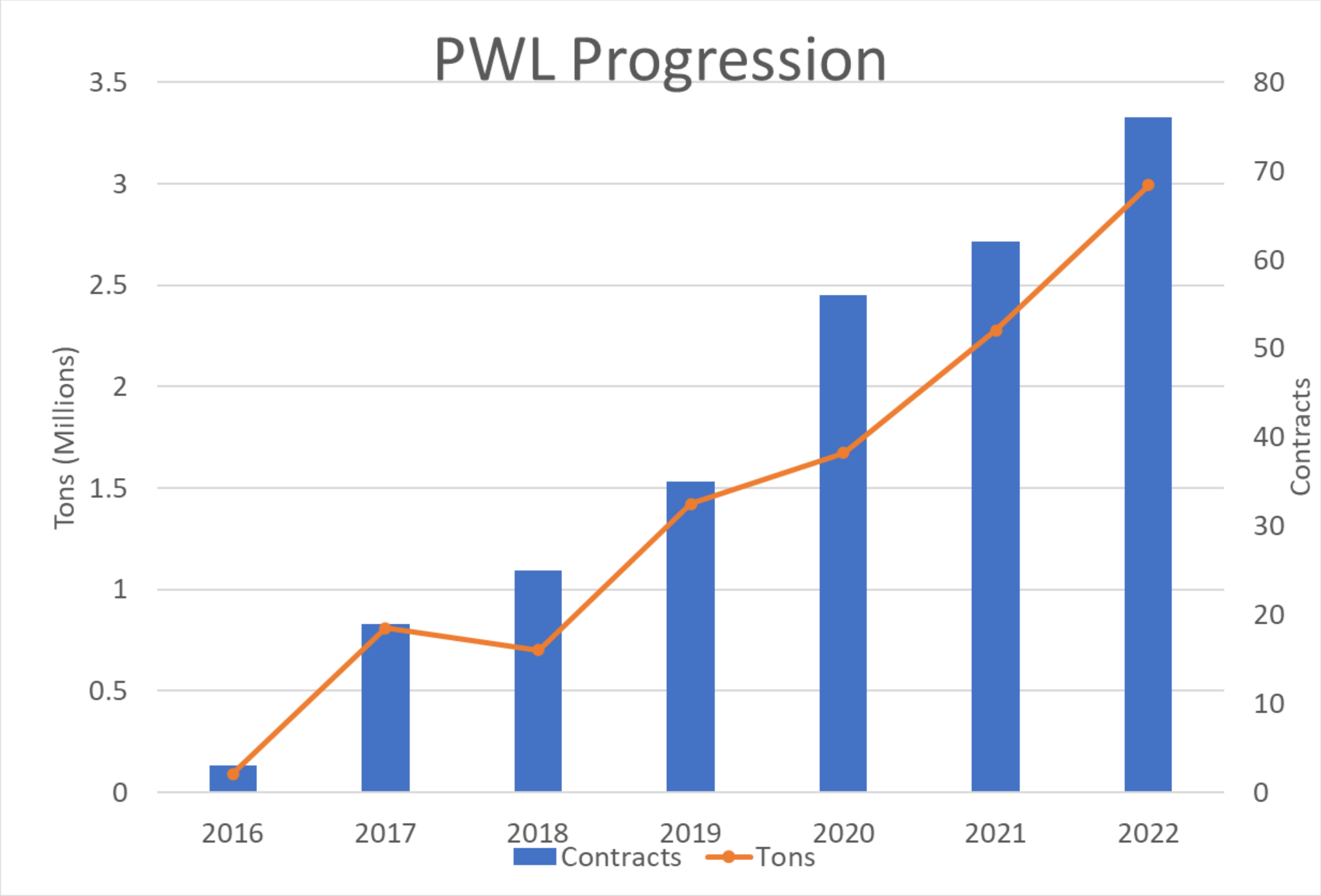
- Overall: longer lasting pavements = greater return on investment

Percent Within Limits





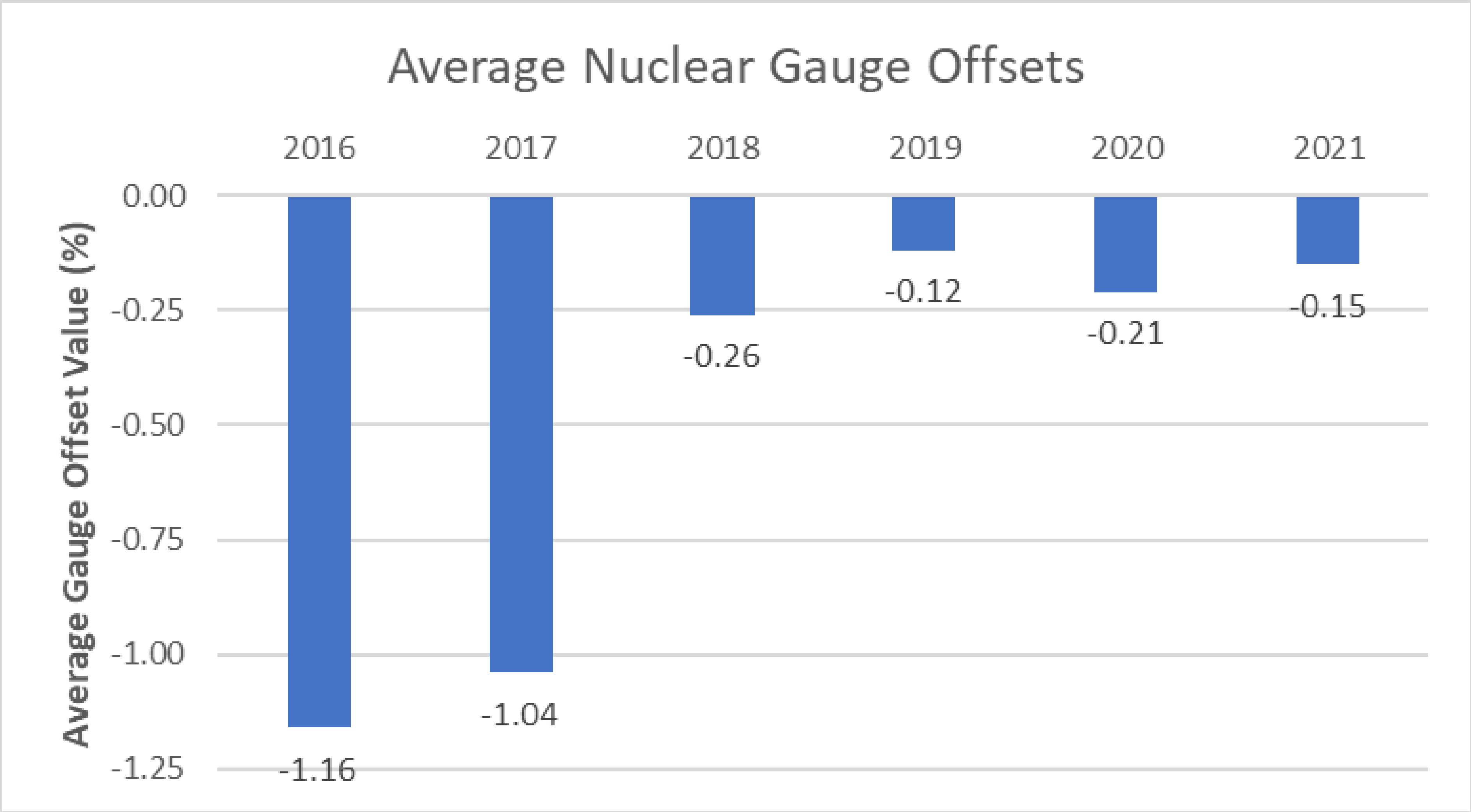
PWL - Percent Within Limits



PWL - Percent Within Limits

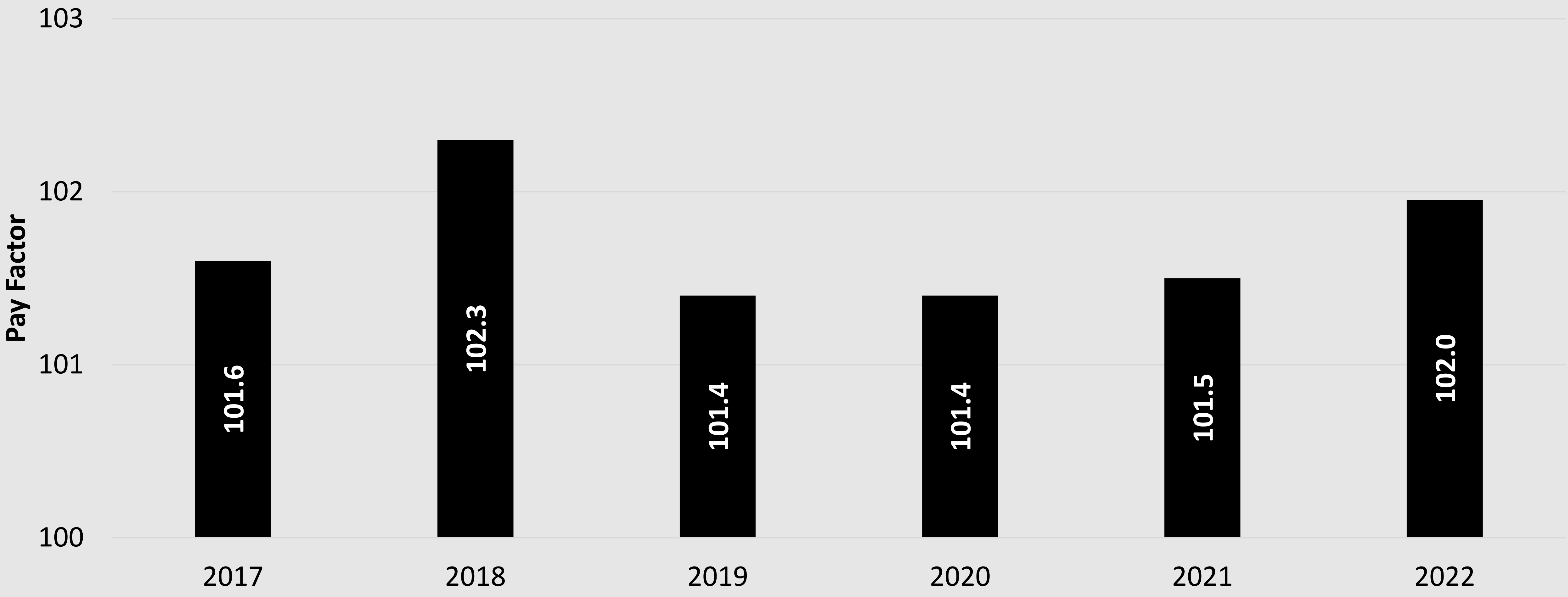
	2016	2017	2018	2019	2020	2021	2022
Number of PWL Contracts	3	19	25	35	56	62	76
Tons	91K	811K	701K	1,423K	*1,673K ~55% of program*	*2,278K ~65% of program*	*2,994K ~63% of program*

Gauge offsets

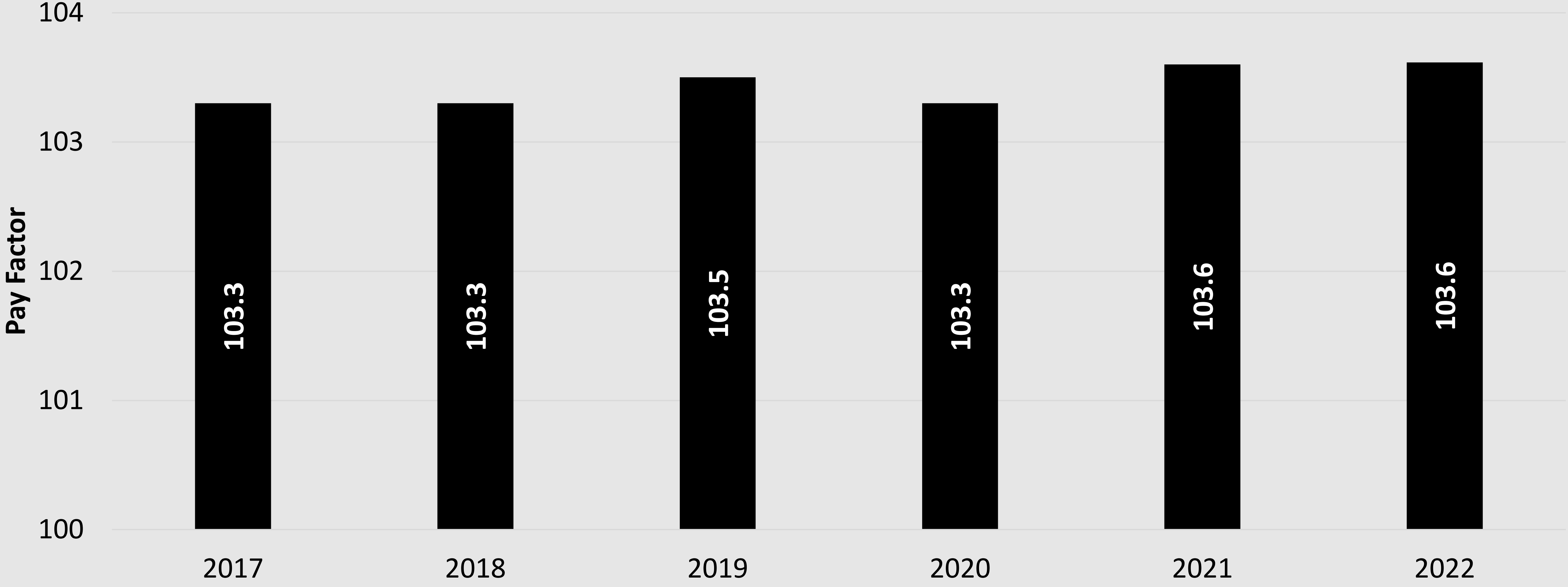


2022 PWL Data Review

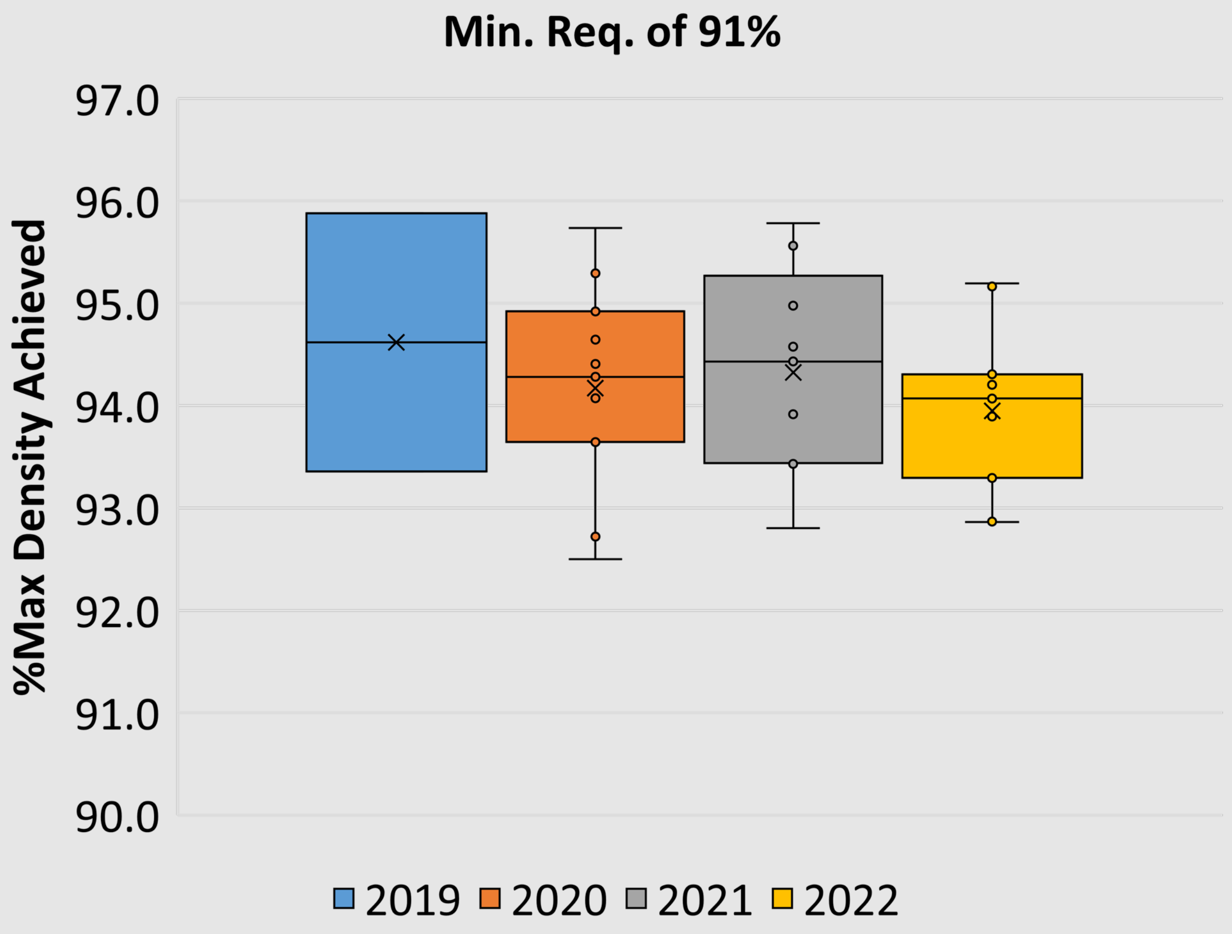
Average Annual Pay Factors - Density

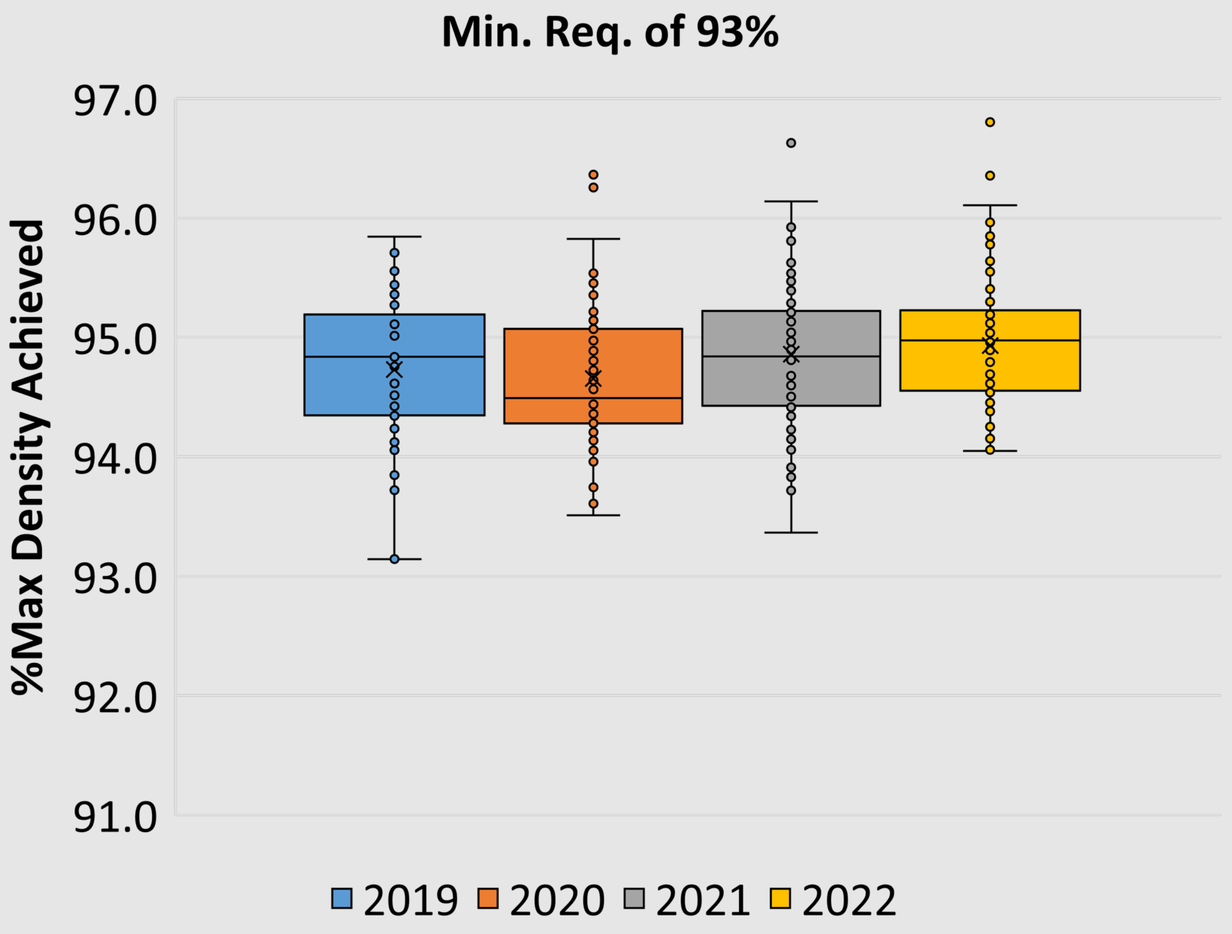


Average Annual Pay Factors – Air Voids

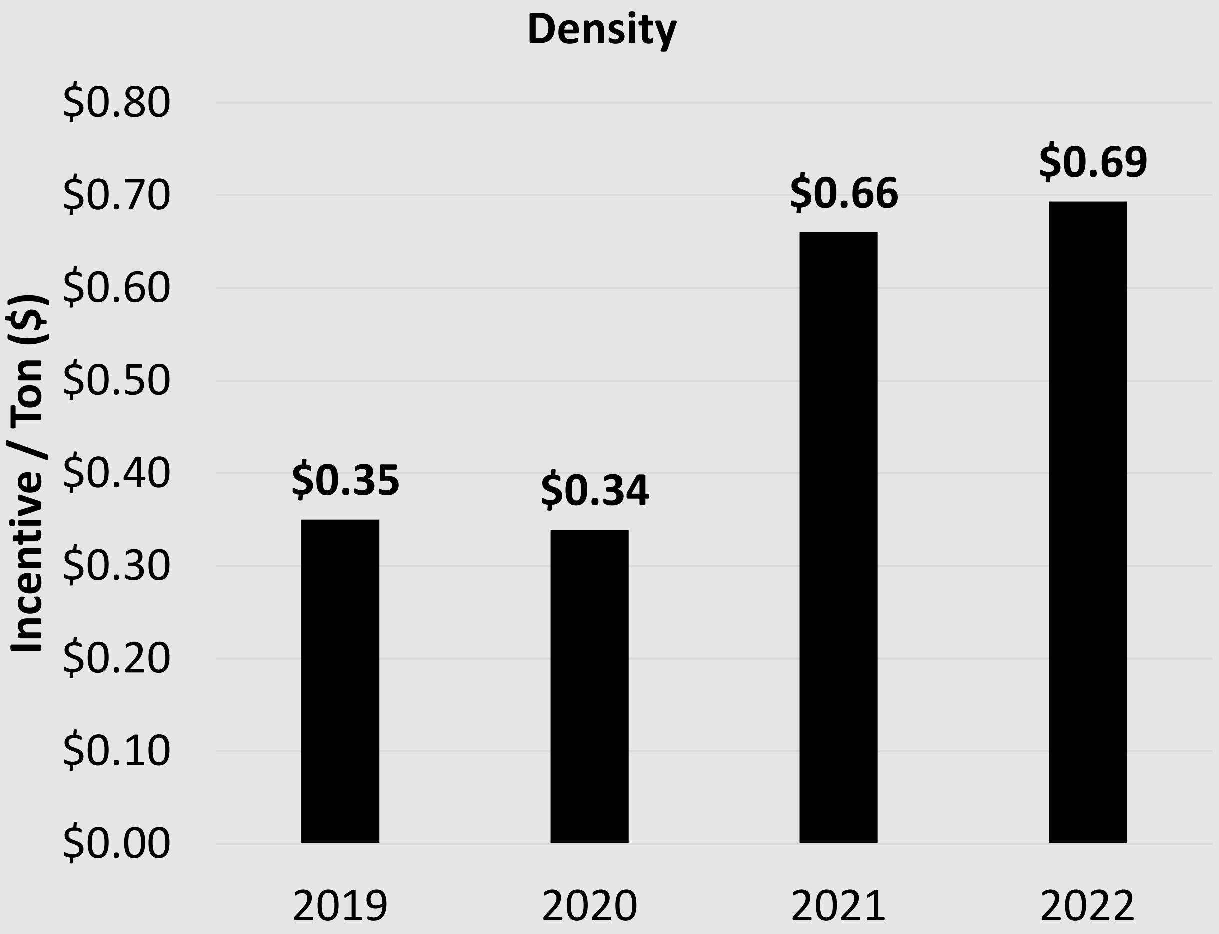


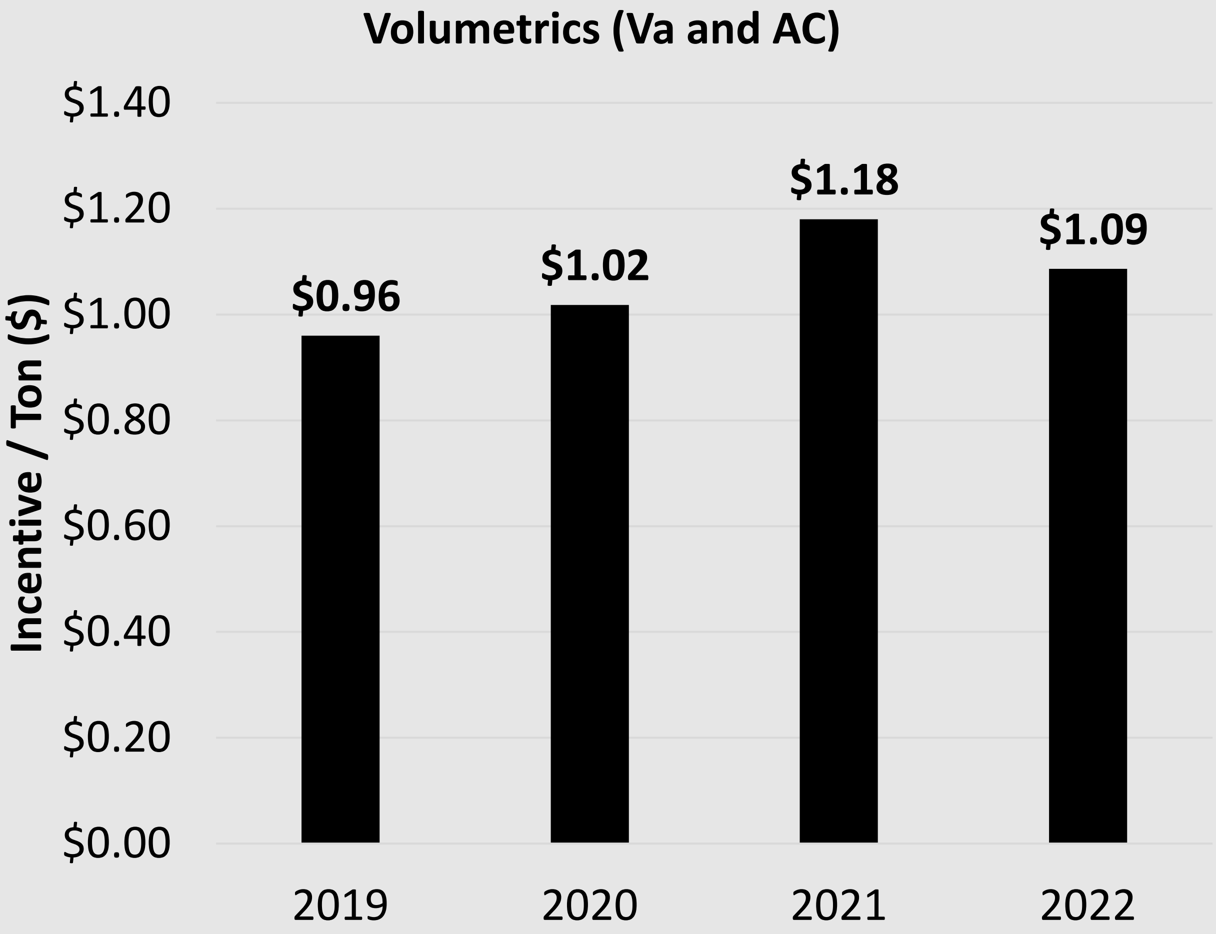
Annual Density Distribution Comparison





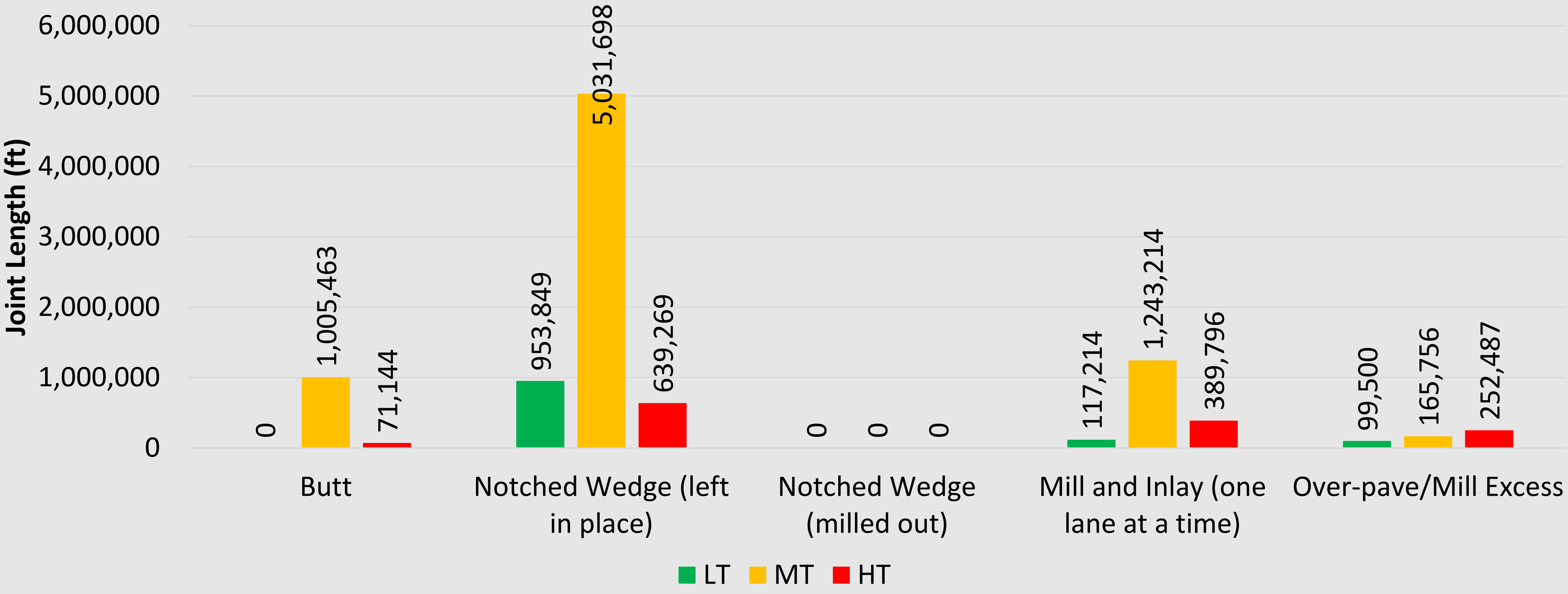
Incentive / Ton



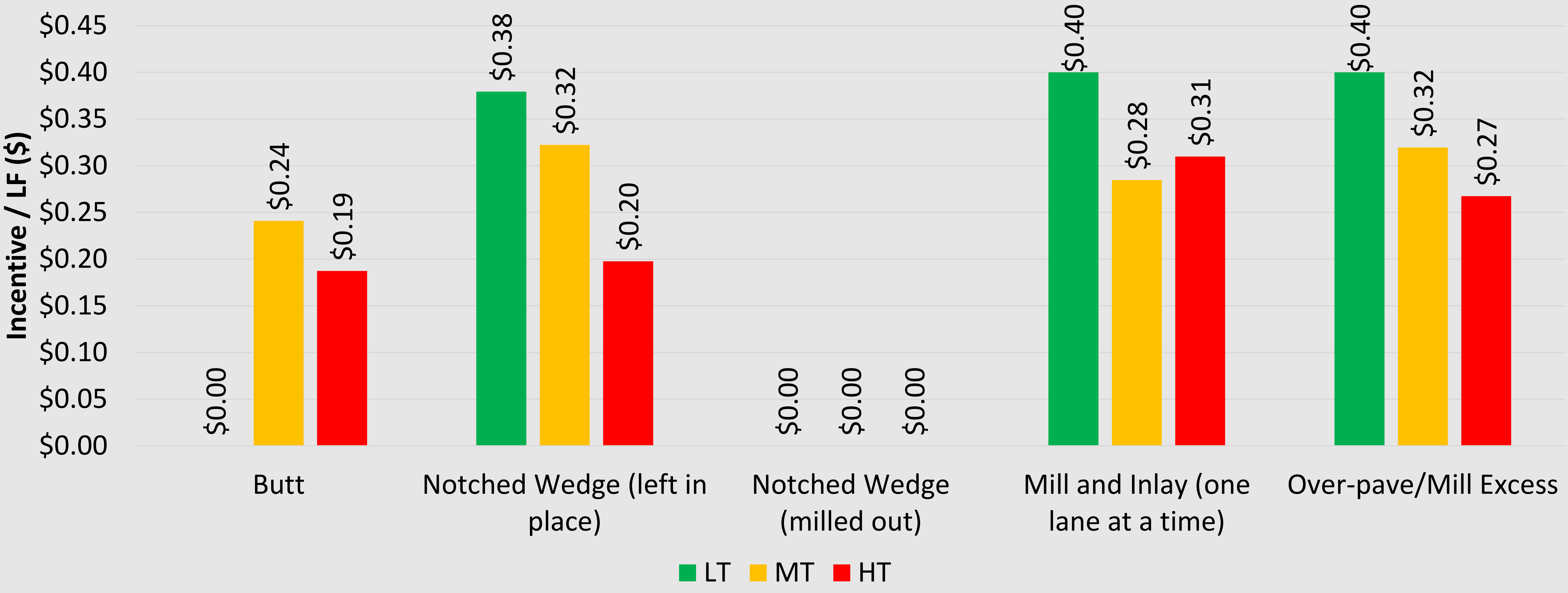


Longitudinal Joint Density

1,888 Miles of Joint Length Paved!

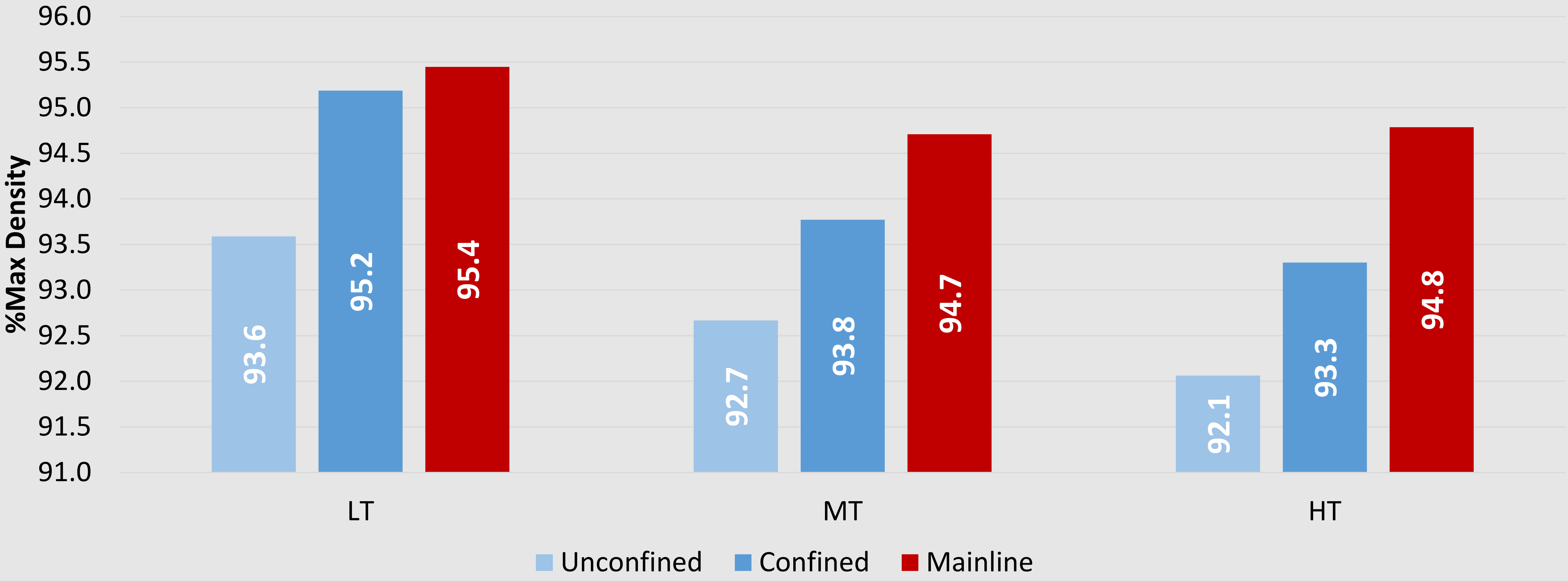


Mill and Inlay and Over-Pave Mill Excess Earn the Most Incentive/LF!



The Laws of Confinement

Unconfined < Confined < Mainline



Tables

Longitudinal Joint Density						
Joint Type	Number of Projects	Total Possible Incentive	Incentive Paid	Joint Length	Incentive/LF	%Max Incentive
Butt	19	$430,642.80	$255,468.40	1,005,669.0	$0.25	59.3%
Notched Wedge (left in place)	74	$2,649,926.35	$2,109,929.81	6,035,502.7	$0.35	79.6%
Notched Wedge (milled out)	0	$-	$-	0.0	N/A	N/A
Mill and Inlay (one lane at a time)	19	$700,089.60	$521,493.60	1,449,354.0	$0.36	74.5%
Over-pave/Mill Excess	7	$207,097.20	$160,259.60	519,743.0	$0.31	77.4%
Combined	119	$3,987,755.95	$3,047,151.41	9,010,268.7	$0.34	76.4%

Background – Density Pay Factor Table

Average Density (%)	Pay Factor							
96.0	104.00	104.00	104.00	104.00	104.00	104.00	103.91	103.60
95.5	104.00	104.00	104.00	104.00	104.00	103.91	103.51	102.77
95.0	104.00	104.00	104.00	104.00	103.91	103.35	102.33	101.10
94.5	104.00	104.00	104.00	103.91	103.05	101.52	99.83	97.91
94.0	104.00	104.00	103.91	102.33	99.83	97.04	94.79	92.99
93.5	104.00	103.91	99.83	94.79	91.56	89.43	87.94	86.85
93.0	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
92.5	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
92.0	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Standard Deviation	**0.05**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**

Background – Air Voids Pay Factor Table

Average Air Voids	Pay Factor							
4.3	80.00	80.00	80.00	80.00	80.00	80.00	50.00	50.00
4.2	103.99	87.83	83.94	82.63	81.98	81.58	80.53	50.00
4.0	104.00	101.04	91.58	87.83	85.90	84.71	81.86	50.00
3.8	104.00	104.00	98.41	92.79	89.72	86.81	82.84	50.00
3.6	104.00	104.00	102.89	97.36	93.38	88.15	83.52	50.00
3.4	104.00	104.00	104.00	101.04	95.43	88.94	83.94	80.13
3.2	104.00	104.00	104.00	103.36	96.21	89.27	84.12	80.24
3.0	104.00	104.00	104.00	102.33	95.95	89.17	84.06	80.20
2.8	104.00	104.00	103.99	99.42	94.61	88.61	83.76	80.02
2.6	104.00	104.00	101.04	95.14	91.58	87.55	83.21	50.00
2.4	104.00	103.99	95.14	90.35	87.83	85.89	82.39	50.00
2.2	104.00	95.14	87.83	85.25	83.94	83.16	81.25	50.00
2.0	80.00	80.00	80.00	80.00	80.00	80.00	50.00	50.00
Standard Deviation	**0.05**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**

Where are we headed?

- PWL Lite for lower tonnages
- PWL for SMA
- PWL for Asphalt Content

New HMA QAP Programs

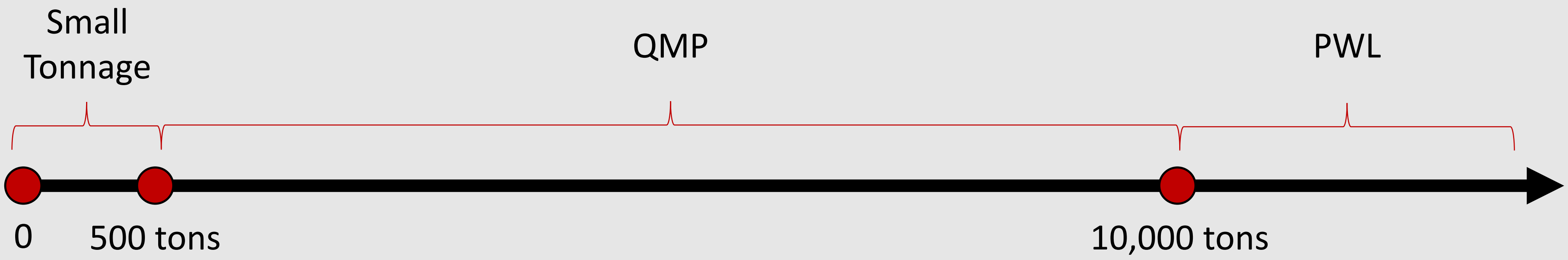
(Replacement for QMP program)

Disclaimer

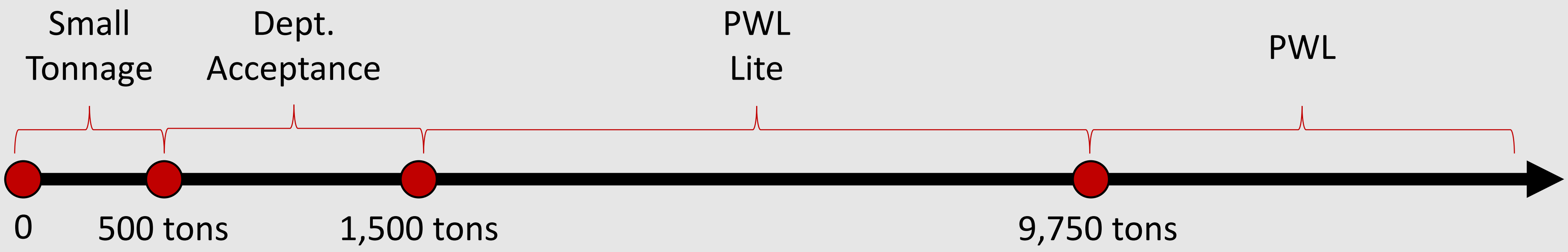
- The concepts presented herein are still works in progress and are subject to change before the final rollout of the new AWP reorganized specifications.

Mixture / Volumetric Testing

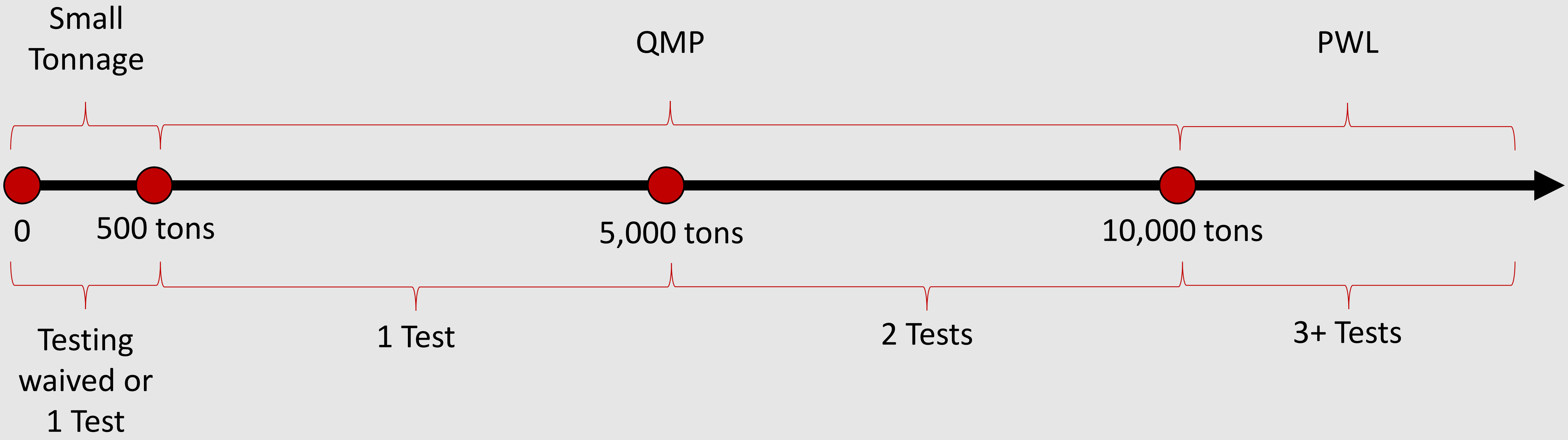
Existing QMP



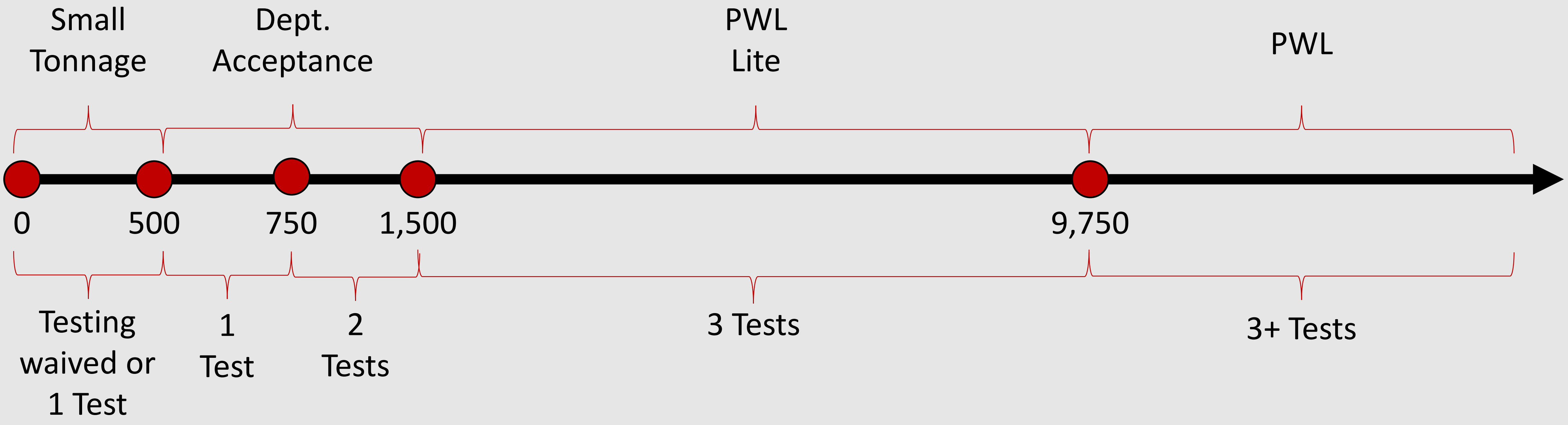
New QAPs



Existing QMP QV Testing Breakdown



New QAP QV Testing Breakdown

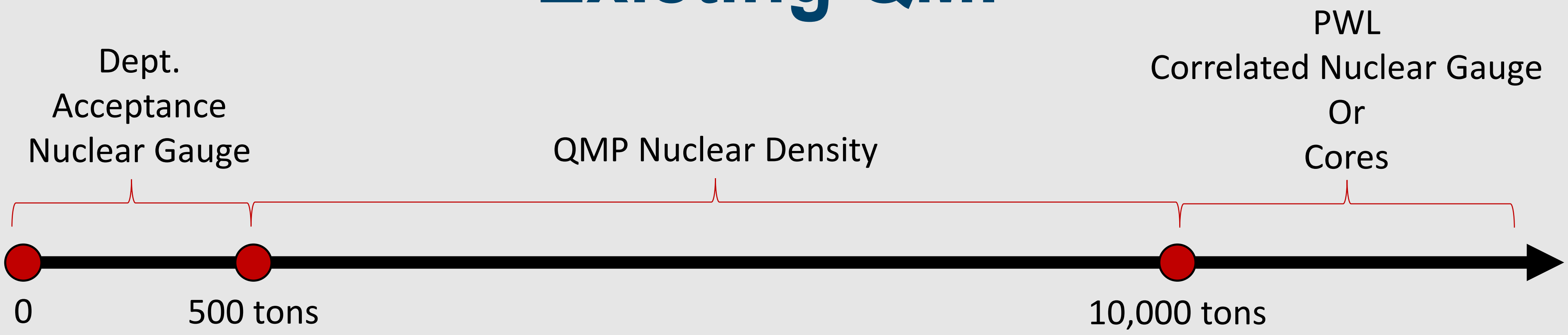


Density Testing

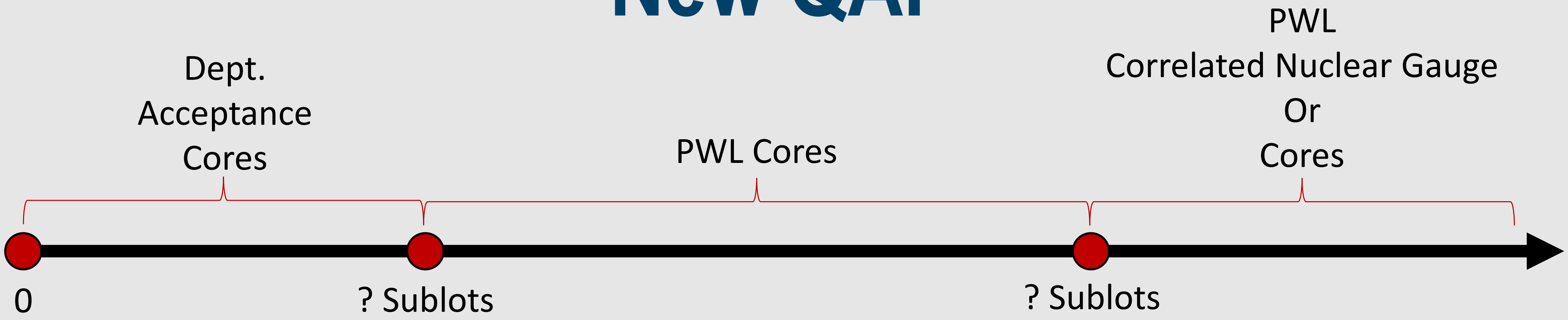
Density / Correlation Test Strips

- **ONLY** required for correlation purposes **when** using a nuclear gauge.
  - Density Correlation/Test Strips to be either 2 density sublots (3,000 LF) or 750 tons.
    - Use 750 tons when performing combined volumetric/density test strip.
    - Use 2 sublots otherwise.

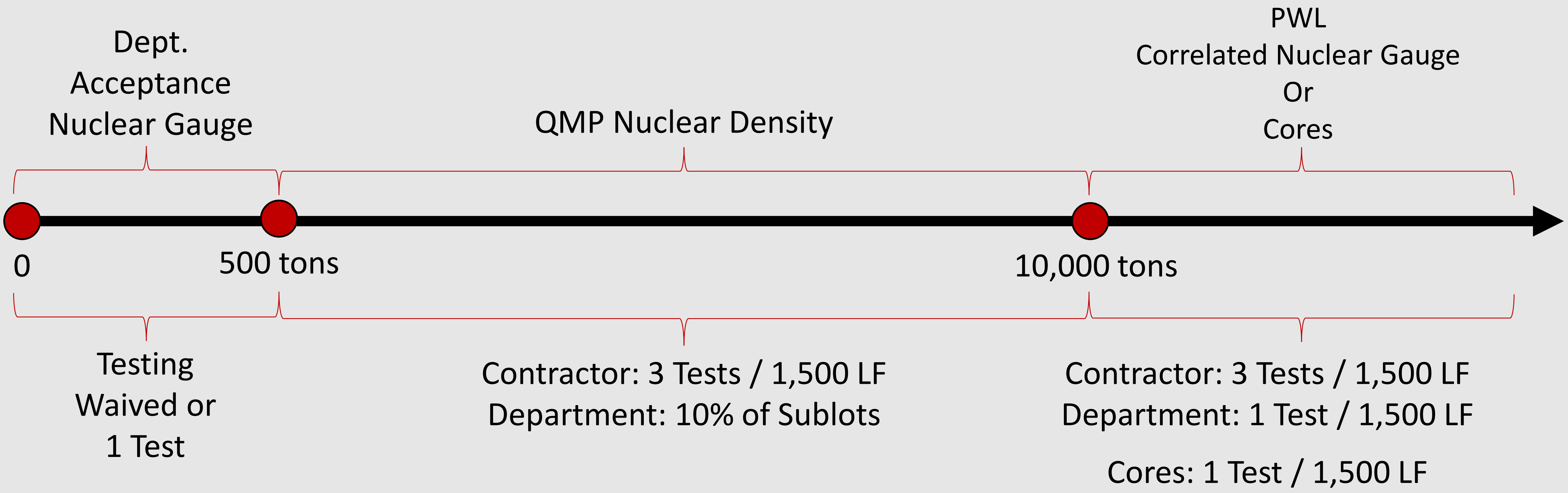
Existing QMP



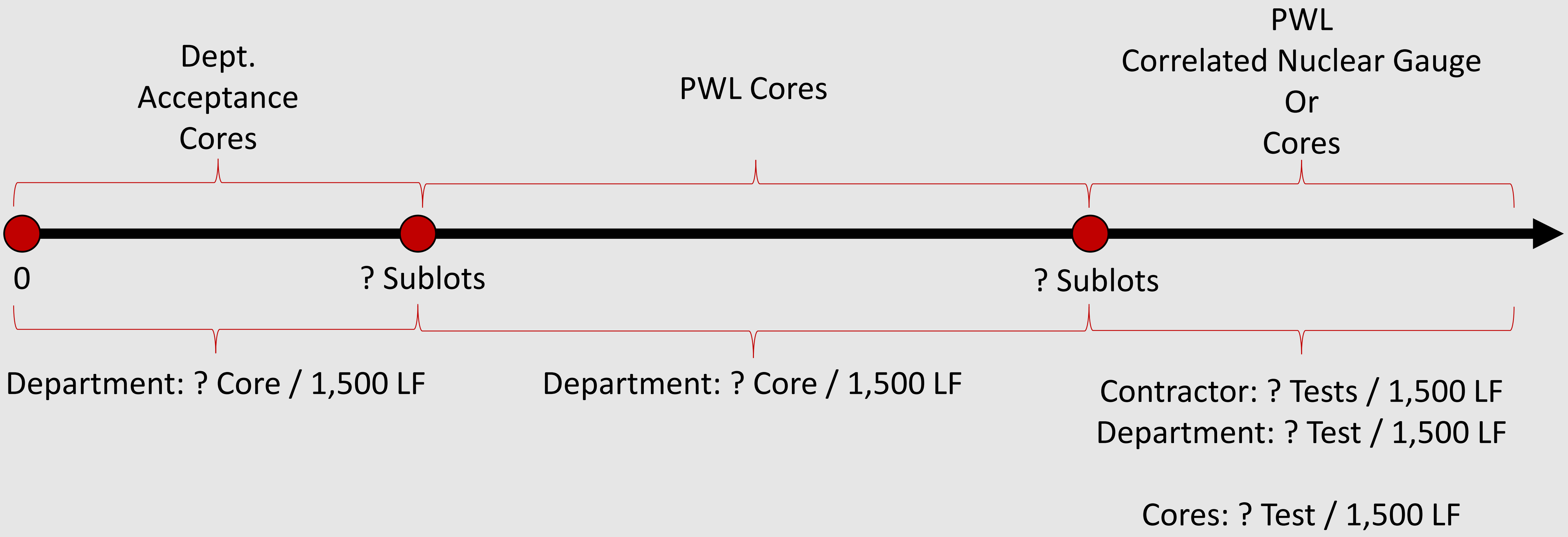
New QAP



QMP Density Testing Breakdown



New Density Testing Breakdown



PWL for SMA

- PWL for SMA
- Review F&t analysis
  - Review potential for additional dispute resolution
- Review air void targets
  - +/-1.3 from 4.5% target? (3.2 – 5.7%)

PWL for Asphalt Content

- PWL for Asphalt Content
  - % Binder or VMA
- Review F&t analysis
  - Review potential for additional dispute resolution
- Review targets
  - -0.3% below JMF

BMD:

An Update on WisDOT's Current Practice and Future Plans

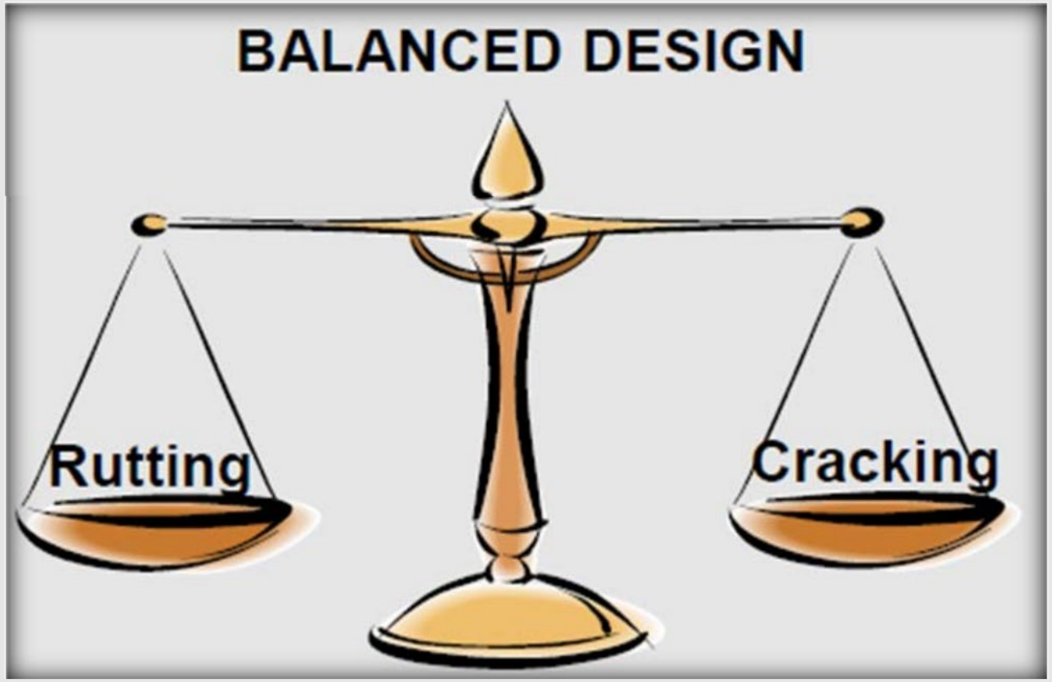
Ali Arabzadeh, PhD, PE

BMD: a method for increasing the durability of asphalt mixtures in WI

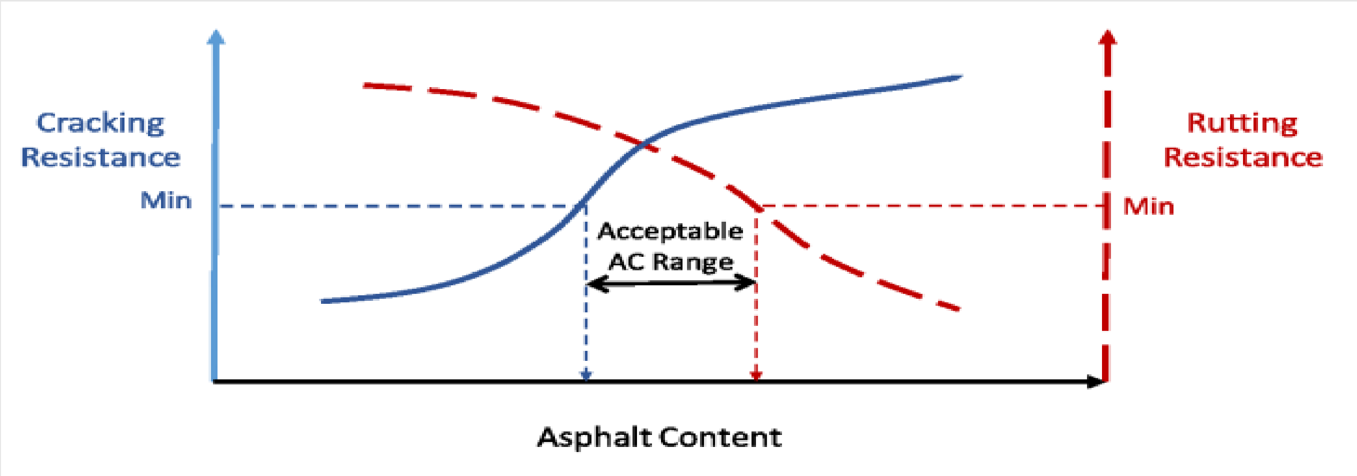
- Balanced Mix Design (BMD)
  - What is BMD?
    - According to Federal Highway Administration (FHWA) Expert Task Group (ETG) BMD Task Force, BMD is “*asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.*”
  - Why do we need BMD?
    - Ensure performance
    - Enable innovation
    - Enable economic optimization

BMD: a method for increasing the durability of asphalt mixtures in WI

- BMD concept
  - A balance between cracking and rutting resistance



Buchanan, 2017



Newcomb et al., 2018

Buchanan, 2017

BMD: a method for increasing the durability of asphalt mixtures in WI

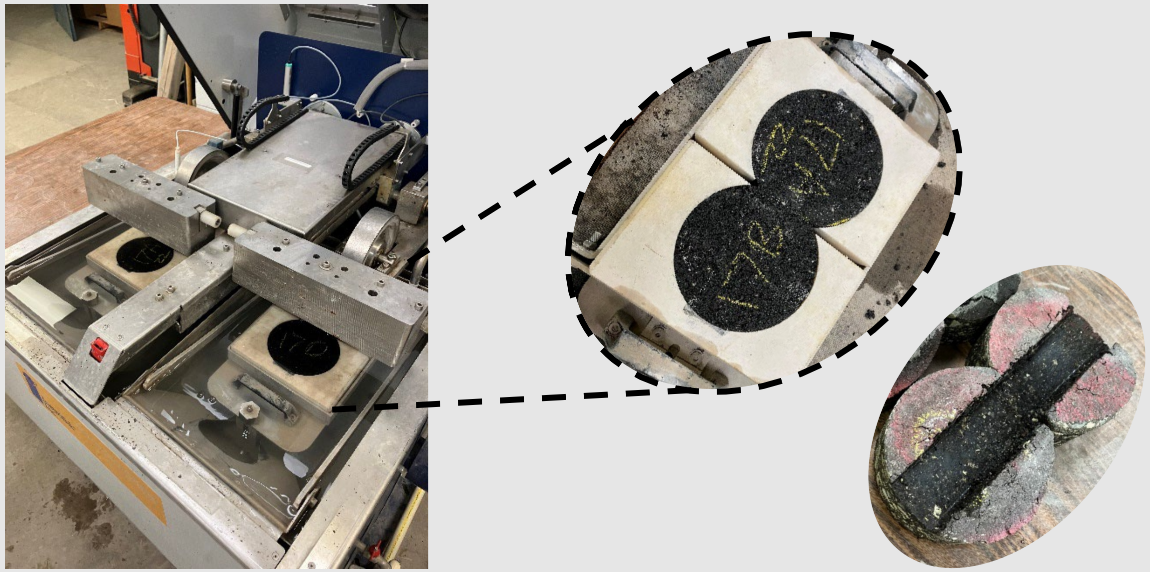
- BMD approaches (currently investigating the appropriateness of Approach A)
  - **Approach A: Volumetric Design with Performance Verification**
    - Starts with an agency approved mix design
    - The mix design is tested with selected mixture rutting and cracking tests
    - If the mix design is failed, the entire mix design is repeated until all the volumetric and performance test criteria are satisfied
  - Approach B: Volumetric Design with Performance Optimization
    - Similar to approach A, except for
    - Testing the performance at OBC and two or more additional binder contents of ± 0.3 to 0.5%
    - Selecting a binder content that satisfies the performance criteria

BMD: a method for increasing the durability of asphalt mixtures in WI

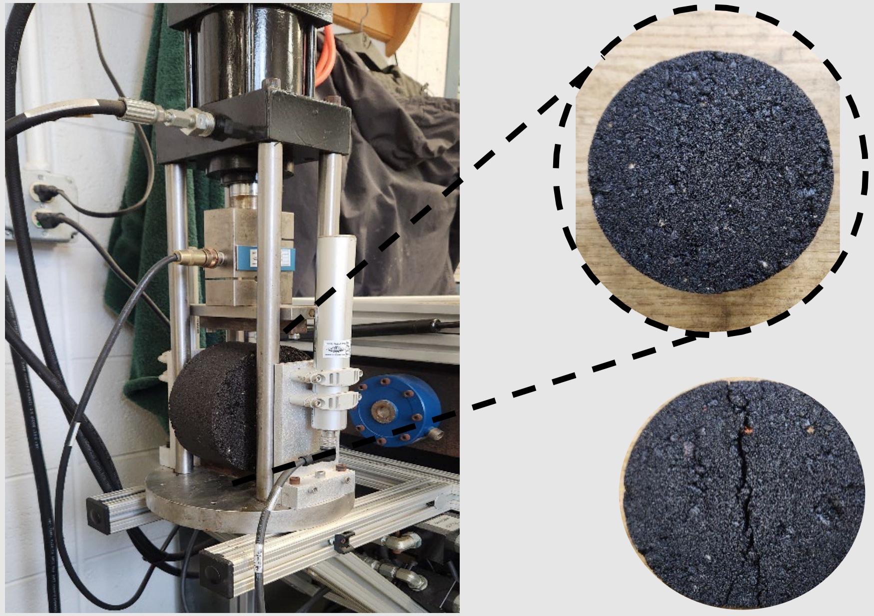
- BMD approaches (currently investigating the appropriateness of Approach A)
  - Approach C: Performance-Modified Volumetric Design
    - Similar to approach A, except for
    - Adjusting the binder content or other mix component properties such as aggregates, binders, recycled materials, and additives.
    - Making sure that certain volumetric properties are in compliance with agency’s relaxed requirements
  - Approach D: Performance Design
    - An existing agency-approved mix design is used
    - The mix design is tested with selected mixture rutting and cracking tests at three or more binder contents at intervals of 0.3 to 0.5 %
    - A binder content that satisfies both the rutting and cracking criteria is selected as the OBC

BMD Performance Tests Used in WI

- There are many different types of performance tests
- WisDOT uses:
  - Hamburg wheel tracking test (HWTT)
  - Indirect tensile asphalt cracking Test (IDEAL-CT)



HWTT @ 46° C



IDEAL-CT @ 25° C

BMD Implementation Train is Unstoppable …

- We have invested substantially and will continue to do so
  - External research
    1. Balanced Mixture Design Implementation Support (status: completed in May 2021)
    2. Balanced Mixture Design Pilot and Field Test Sections (status: under review by WHRP* Flexible Pavements TOC*)
       - $5,000,000 has been spent on BMD-related research!
       - We will have an upcoming WHRP research focusing on Approach C
  - In-house research
    - BMD Benchmarking Experiment
      - WisDOT's Central Office has been investigating the suitability of BMD implementation for about **4 years**!
      - Next step is field validation
- In the future, it can be a tool for justifying the sustainability of unsustainable materials used at the plant
- There will be challenges …
  - We are committed to collaborate with the regions and industry to make the transition as **smooth** as possible

*Note: WHRP and TOC are the abbreviations of Wisconsin Highway Research Program and Technical Oversight Committee.

External Research Project No.1

- *Balanced Mixture Design Implementation Support* (status: completed in May 2021)
  - A benchmarking experiment was conducted by NCAT* researchers to establish preliminary performance criteria
  - 18 Total mix designs were tested.
    - Thirteen 12.5-mm mixes
      - Three HT Mixes (PG 58-28S)
      - Five MT Mixes (PG 58-28S)
      - Four LT Mixes (PG 58-28S)
      - One SMA (PG 58-28V)
    - Five 9.5-mm mixes
      - Four MT Mixes (3 - PG 58-28S and 1 - PG 52-34S)
      - One LT Mix (PG 58-28S)


Balanced Mixture Design Implementation Support

Randy West
Fan Yin
Carolina Rodezno
Adam Taylor

National Center for Asphalt Technology at Auburn University

WisDOT ID no. 0092-20-04

March 2021

Research & Library Unit

WHRP
Wisconsin Highway Research Program

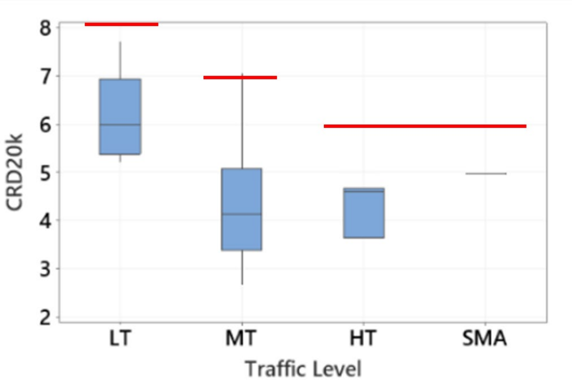
WISCONSIN DOT
PUTTING RESEARCH TO WORK

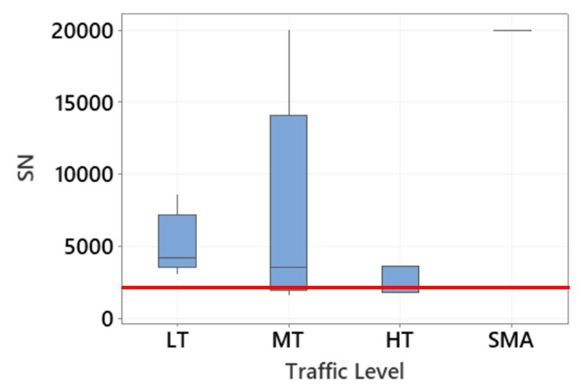
https://wisconsindot.gov/documents2/research/0092-20-04-final-report.pdf

*Note: NCAT is the abbreviation for National Center for Asphalt Technology.

External Research Project No. 1

- The NCAT researchers suggested preliminary performance criteria:
  - HWTT
    - Since rutting has not been a problem for Wisconsin, the **CRD*$_{20k}$** criteria were selected such that nearly all mixes in the benchmarking experiment pass the respective criteria
      - Based upon a rounded maximum value from the results for each traffic level
      - HT and SMA criteria were slightly relaxed from the maximum value due to uncertainty from the small datasets for these traffic levels (15 - 25% higher than the observed maximum value)
    - A minimum of 2,000 passes was suggested for **SN* for** all mixes based on the findings of Yin et al. (2020), which indicated that the threshold successfully discriminated asphalt mixes with and without moisture damage





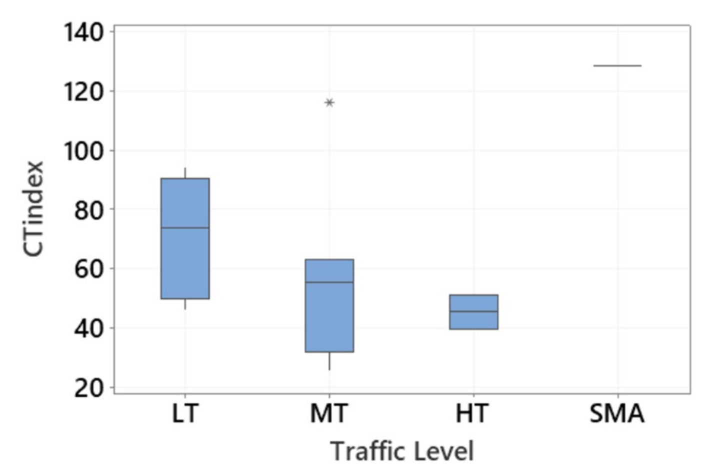
Traffic Level	HWTT*	
	CRD_{20k} (mm)	*SN* (passes)
SMA Mix	≤ 6.0	≥ 2,000
HT Mix		
MT Mix	≤ 7.0	
LT Mix	≤ 8.0	

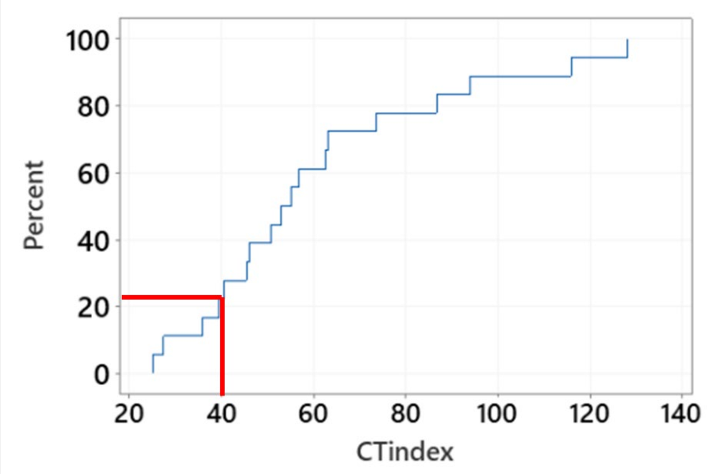
https://wisconsindot.gov/documents2/research/0092-20-04-final-report.pdf

*Note: CRD and SN are the abbreviations of corrected rut depth and stripping number.

External Research No. 1

- The NCAT researchers suggested preliminary performance criteria:
  - IDEAL-CT
    - Different traffic levels are designed with different N_{design}, , which results in different asphalt binder contents.
    - **CT***$_{Index}$ is highly dependent on the asphalt binder content of the mix
    - A minimum CT_{Index} of 40 was suggested for all traffic levels (LT, MT, HT)
      - Based upon the 25th percentile (40.4 CTIndex) of all mixtures benchmarked
    - SMA criteria was set at 80 CTIndex to ensure superior cracking resistance as a premium asphalt mixture



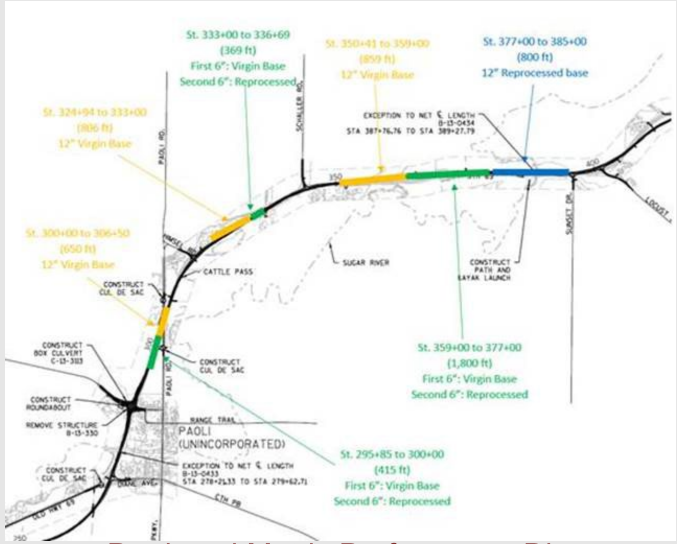


https://wisconsindot.gov/documents2/research/0092-20-04-final-report.pdf

*Note: CT is the abbreviation of cracking tolerance.

External Research No. 2

- For part one of the research, the NCAT researchers suggested the construction of 6 test section:
  - To establish correlation between BMD test results and field performance
    - Test sections had a range of expected field performance

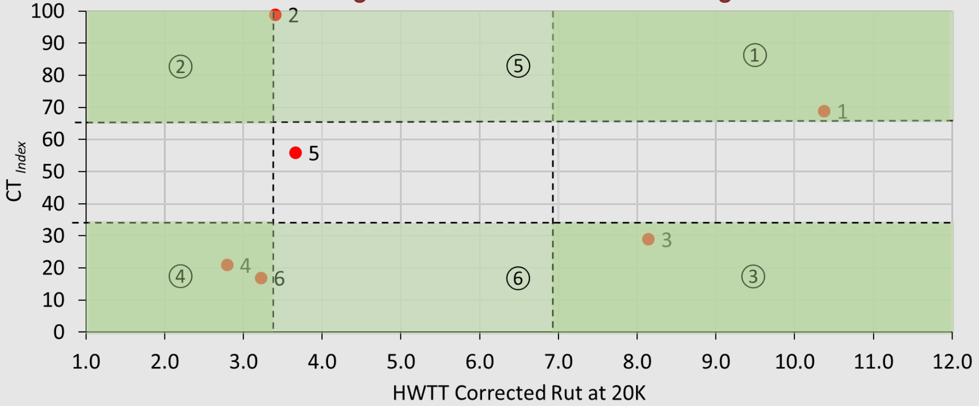


Experimental Matrix

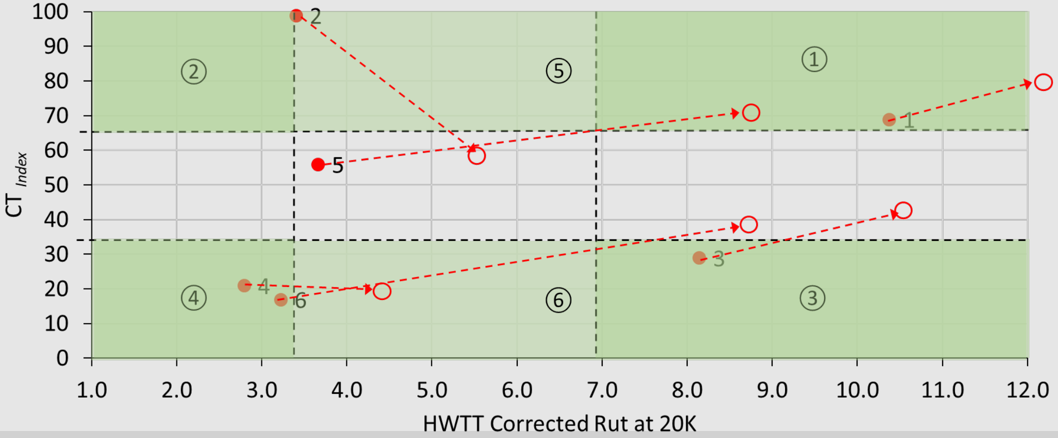
HWTT Corrected Rut Depth	IDEAL CT_{Index} (after 6-hours @ 135°C aging)	
	> 65	< 35
> 7.0 mm	①	③
< 3.5 mm	②	④
V-grade binder	⑤	⑥

[1] Section identical to mixture design 1 with "V" binder replacing "S" binder
[2] Section identical to mixture design 3 with "V" binder replacing "S" binder

Mix Design Matrix Performance Diagram

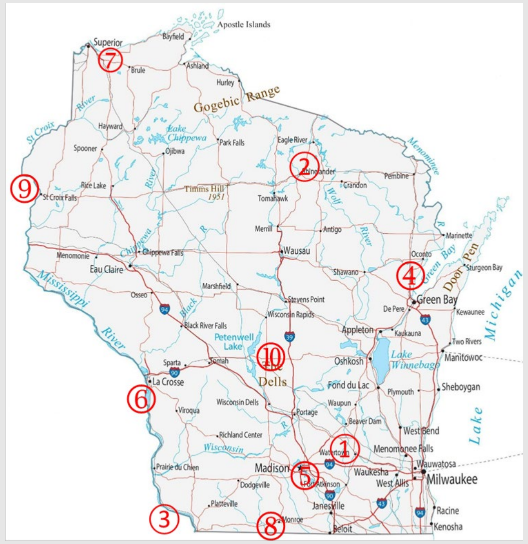


Produced Matrix Performance Diagram



External Research No. 2

- For part 2 of the research, the NCAT researchers obtained loose mixes from 10 shadow projects
  - To obtain representative data
- Mixes represent the state's diversity in aggregate type, binder grades, and mix type
- Contractors obtained mix samples from two or three full lots from each shadow project
- NCAT conducted HWTT, IDEAL-CT, etc. on samples
  - Summary of within-lot variability for BMD test results



IDEAL CT

Project	Lot	Average	Std. Dev	COV
1	1	47.0	7.4	15.6%
	2	48.0	4.0	8.4%
2	2	58.2	9.1	15.7%
	3	62.8	19.6	31.1%
3	2	62.7	6.4	10.2%
	3	69.7	27.7	39.7%
	4	73.3	17.8	24.3%
4	2	86.2	7.6	8.8%
	3	83.8	10.7	12.8%
	4	89.0	6.0	6.7%
5	4	40.1	4.3	10.7%
	5	44.3	8.8	19.9%
	6	51.3	5.2	10.1%
6	9 & 11	46.2	3.6	7.8%
	10	51.2	7.7	15.1%
7	3 & 6	106.7	16.8	15.7%
	4	113.5	7.8	6.9%
	5	120.4	8.9	7.4%
8	3	45.1	2.0	4.4%
	4	51.0	4.6	9.1%
	5	43.4	0.6	1.3%
9	8	51.5	8.9	17.2%
	9	58.9	5.2	8.8%
	10	57.5	5.5	9.5%
10	[illegible]	[illegible]	[illegible]	[illegible]

Minimum COV: 1.3%
Mean COV: 13.1%
Maximum COV: 39.7%

HWTT - Corrected Rut Depth 20,000 passes

Project	Lot	Average	Std. Dev	COV
1	1	10.7	2.2	20.4%
	2	11.0	1.4	13.1%
2	2	16.4	2.8	16.8%
	3	16.2	0.7	4.4%
3	2	9.0	0.4	4.1%
	3	11.0	0.4	4.1%
	4	10.6	1.2	11.7%
4	2	15.9	1.6	10.3%
	3	16.2	1.3	8.0%
	4	17.3	3.0	17.6%
5	4	10.5	1.0	9.9%
	5	11.2	0.7	5.8%
	6	10.5	0.7	7.0%
6	9 & 11	11.3	1.0	8.7%
	10	11.6	1.6	13.5%
7	3 & 6	11.7	0.7	5.6%
	4	13.1	3.4	26.4%
	5	16.4	3.3	20.1%
8	3	10.2	1.2	11.9%
	4	10.2	1.0	10.0%
	5	8.4	1.2	14.3%
9	8	9.7	0.9	9.3%
	9	11.0	1.1	9.6%
	[illegible]	[illegible]	[illegible]	10.6%
10	[illegible]	[illegible]	[illegible]	[illegible]

Minimum COV: 4.1%
Mean COV: 10.9%
Maximum COV: 26.4%

SN

Project	Lot	Average LC_{SN}	Std. Dev. LC_{SN}	COV
1	Lot 1	4342	1868	43.0%
	Lot 2	3644	1135	31.1%
2	Lot 2	4232	1692	40.0%
	Lot 3	3188	1356	42.5%
3	Lot 2	6011	3483	57.9%
	Lot 3	4348	935	21.5%
	Lot 4	4424	1002	22.6%
4	Lot 2	3101	797	25.7%
	Lot 3	4502	1898	42.2%
	Lot 4	3089	1638	53.0%
5	Lot 4	7997	2723	34.1%
	Lot 5	5743	3587	62.5%
	Lot 6	5828	2706	46.4%
6	Lot 9&11	3289	487	14.8%
	Lot 10	4045	1819	45.0%
7	Lot 3&6	2530	440	17.4%
	Lot 4	2426	590	24.3%
	Lot 5	2476	203	8.2%
8	Lot 3	2995	951	31.8%
	Lot 4	3138	1205	38.4%
	Lot 5	3150	770	24.4%
9	Lot 8	3955	1149	29.1%
	Lot 9	3460	860	24.9%
	[illegible]	[illegible]	[illegible]	35.0%
10	[illegible]	[illegible]	[illegible]	22.5%
	[illegible]	[illegible]	[illegible]	42.0%
	[illegible]	[illegible]	[illegible]	23.4%

Minimum COV: 8.2%
Mean COV: 33.5%
Maximum COV: 62.5%

- Contractors provided asphalt and air void contents
  - Summary of within-lot variability

Asphalt Content

Project	Lot	Average	Std. Dev.	COV
1	1	6.1	0.2	2.6%
	2	6.3	0.2	3.8%
2	2	5.6	0.1	1.3%
	[illegible]	[illegible]	[illegible]	[illegible]

Minimum COV: 1.3%
Mean COV: 2.8%
Maximum COV: 7.2%

Air Voids

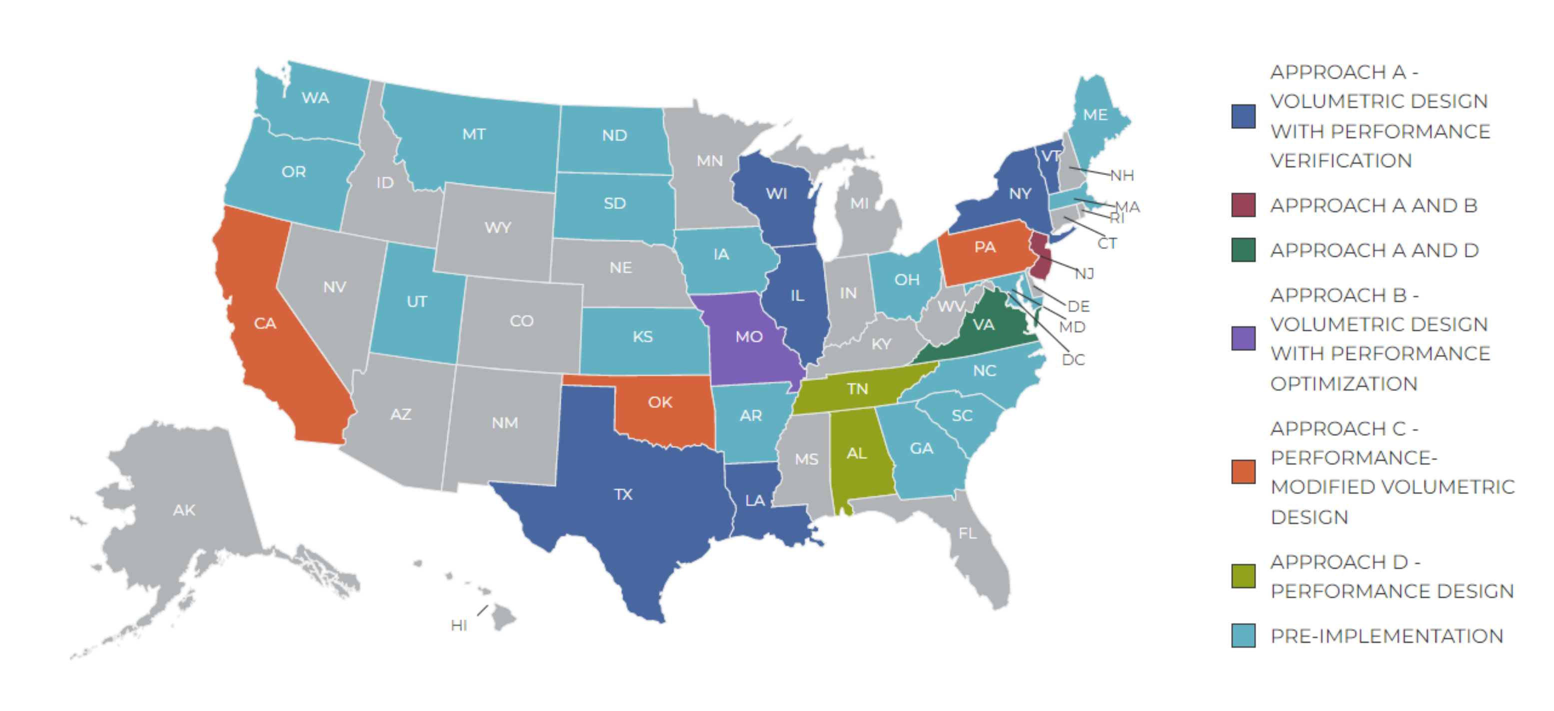
Project	Lot	Average	Std. Dev.	COV
1	1	3.3	0.4	12.8%
	2	3.1	0.3	10.2%
2	2	2.8	0.1	4.1%
	[illegible]	[illegible]	[illegible]	[illegible]

Minimum COV: 1.7%
Mean COV: 10.4%
Maximum COV: 21.3%

BMD Pilot Projects in WI

- How do we compare with others?
  - In 2020, WisDOT developed an SPV for BMD pilot projects selected from percent within limits (PWL) projects
    - One pilot project per region
    - Mix design stage, not production
    - HWTT and IDEAL-CT

Implementation Efforts

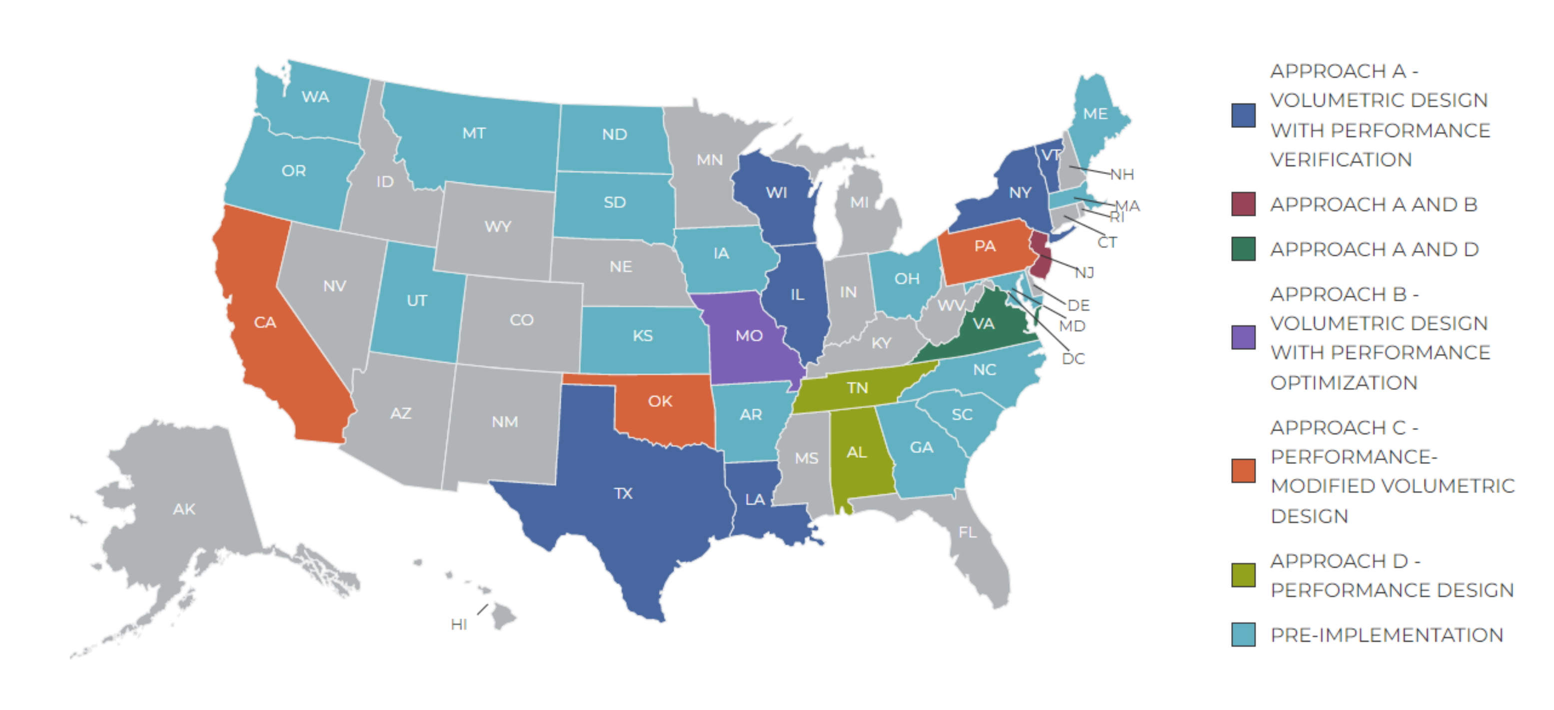


https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide/implementation-efforts

BMD Pilot Projects in WI

- How do we compare with others?
  - WisDOT developed an SPV for BMD pilot projects selected from PWL projects
    - From 2021-2023: the criteria set for HWT test were based on **No. of passes to failure** and **SIP**
    - From 2023-present: the criterial set for HWT have been based on **CRD** and **SN**

Implementation Efforts



*Note: SIP is the abbreviation of stripping inflection point.

https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide/implementation-efforts

BMD Pilot Projects in WI

- SPV used for pilot BMD projects since 2020

HMA Pavement Balanced Mix Design

A Description

Conform to standard specification 450 and 460 except as modified in this special provision.

This special provision incorporates balanced mix design (BMD) into the mix design procedures specified in standard specification 460. This specification applies to the primary upper layer mixture under the following bid item: Enter Bid Item #. Mix designs will be tested by the Hamburg Wheel-Track Test (HWT) according to AASHTO T 324 as modified by CMM 836.6.10.1 and the Indirect Tensile Cracking Test at Intermediate Temperature (CT-Index) according to ASTM D8225 as modified by CMM 836.6.10.2.

  - BMD is incorporated at the mix design stage for certain PWL projects
  - Applies to upper layer mixtures
  - Mix designs are tested using HWTT and IDEAL-CT methods

BMD Pilot Projects in WI

- SPV used for pilot BMD projects since 2020
  - Mix design testing criteria from 2021 to 2023

Binder Designation Level[1]	S	H	V	E
~~Hamburg Wheel Tracking (AASHTO T 324 as modified in CMM 836.6.10.1) Passes to 12.5 mm rut depth Stripping Inflection Point~~	~~10,000 8,000~~	~~[illegible] 8,000~~	~~20,000 8,000~~	~~20,000 8,000~~
IDEAL-CT[2] (ASTM D8225 as modified in CMM 836.6.10.2) CT-Index	30	30	30	30

To ensure rutting and moisture damage resistance

To ensure cracking resistance

  - Mix design testing criteria from 2023 to present

Mixture Type	LT	MT	HT	SMA
Hamburg Wheel Tracking (WTM T324) Corrected Rut Depth @ 20,000 Passes (mm) Stripping Number (LC_{SN})	≤ 12.0 ≥ 3,000	≤ 7.5 ≥ 3,000	≤ 5.0 ≥ 3,000	≤ 4.0 ≥ 3,000
IDEAL-CT (ASTM D8225 as modified in CMM 836.6.10.2) CT-Index	≥ 30	≥ 30	≥ 30	≥ 80

To ensure rutting and moisture damage resistance

To ensure cracking resistance

  - Testing during the production was for information purpose only

BMD Shadow Projects in WI

- Loose mixture were procured from:
  - PWL projects from 2020 to 2023
  - Certain PWL and non-PWL projects since 2023
- BMD performance tests
  - IDEAL-CT
  - HWTT
- Participants
  - Department (Central Office)
  - Contractors
- Results from 287 mixtures have been analyzed so far

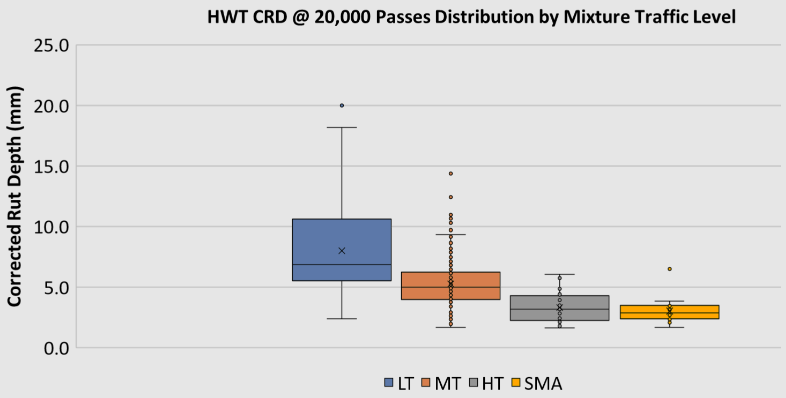
BMD Shadow Projects in WI

- HWTT was conducted @ 46°C on
  - Short-term aged (reheated) mixtures
- IDEAL-CT was conducted @ 25°C on
  - Both reheated and long-term aged mixtures
- No. of specimens fabricated per mixture
  - Reheated (@ 135°C for 2 hours)
    - HWTT: 4 specimens
    - IDEAL-CT: 4 specimens
  - Long-term aged (@ 135°C for 6 hours)
    - IDEAL-CT: 4 specimens
  - Total number of specimens tested by 2023: 287X3X4 = **3,444**

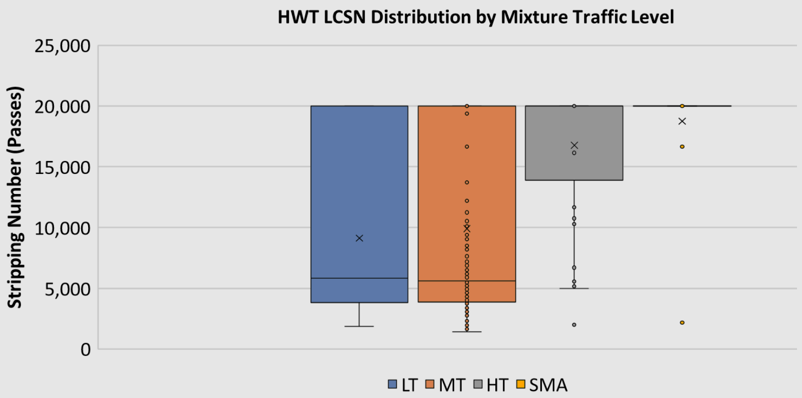
BMD Shadow Projects in WI

- The influence of traffic level and/or aggregate skeleton on BMD test results

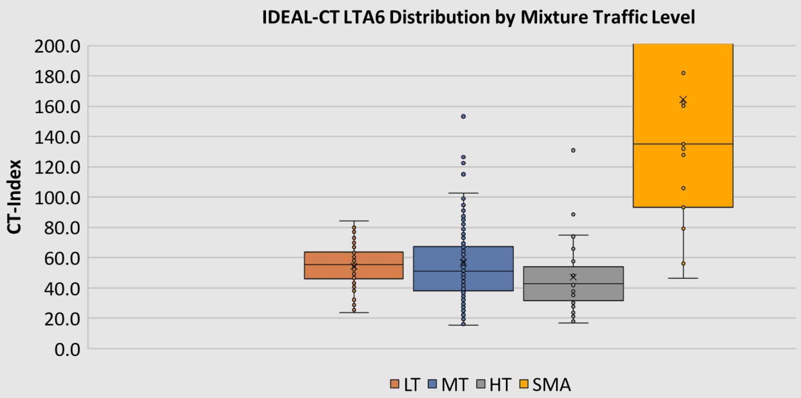
Corrected Rut Depth (CRD)



Stripping Number (SN)



CT-Index



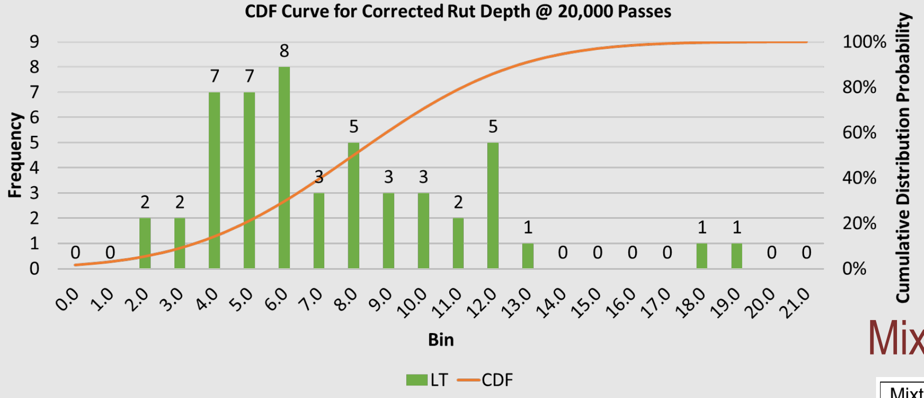
Mix design testing criteria from 2023 to present

Mixture Type	LT	MT	HT	SMA
Hamburg Wheel Tracking (WTM T324)				
Corrected Rut Depth @ 20,000 Passes (mm)	≤ 12.0	≤ 7.5	≤ 5.0	≤ 4.0
Stripping Number (LC_{SN})	≥ 3,000	≥ 3,000	≥ 3,000	≥ 3,000
IDEAL-CT (ASTM D8225 as modified in CMM 836.6.10.2) CT-Index	≥ 30	≥ 30	≥ 30	≥ 80

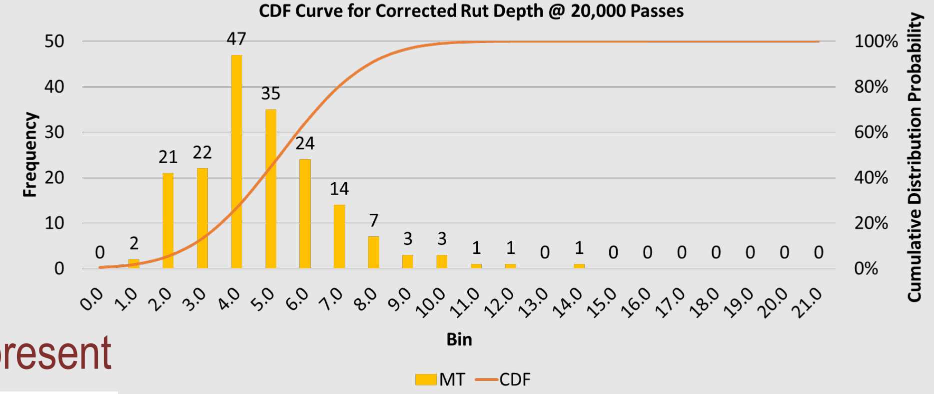
BMD Shadow Projects in WI

- CRD cumulative distribution function (CDF) curves

LT



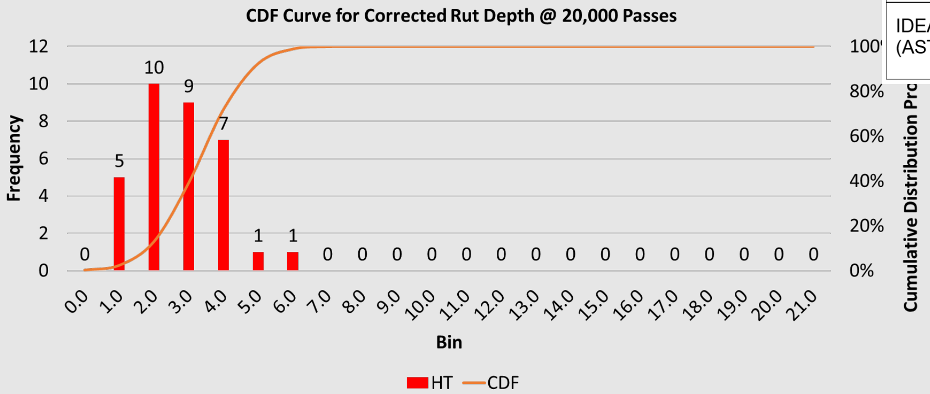
MT



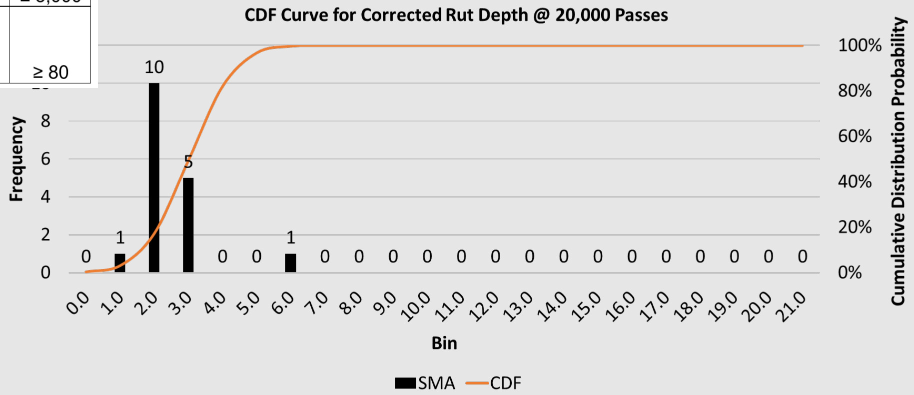
Mix design testing criteria from 2023 to present

Mixture Type	LT	MT	HT	SMA
Hamburg Wheel Tracking (WTM T324)				
Corrected Rut Depth @ 20,000 Passes (mm)	≤ 12.0	≤ 7.5	≤ 5.0	≤ 4.0
Stripping Number (LC_{SN})	≥ 3,000	≥ 3,000	≥ 3,000	≥ 3,000
IDEAL-CT (ASTM D8225 as modified in CMM 836.6.10.2)				
CT-Index	≥ 30	≥ 30	≥ 30	≥ 80

HT



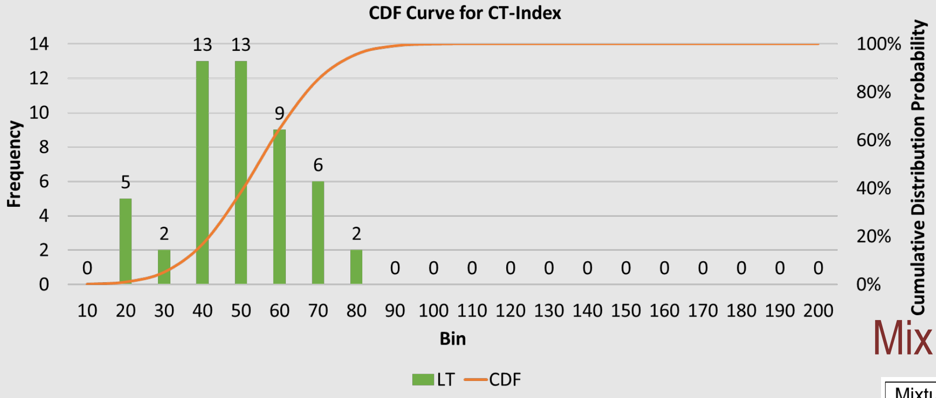
SMA



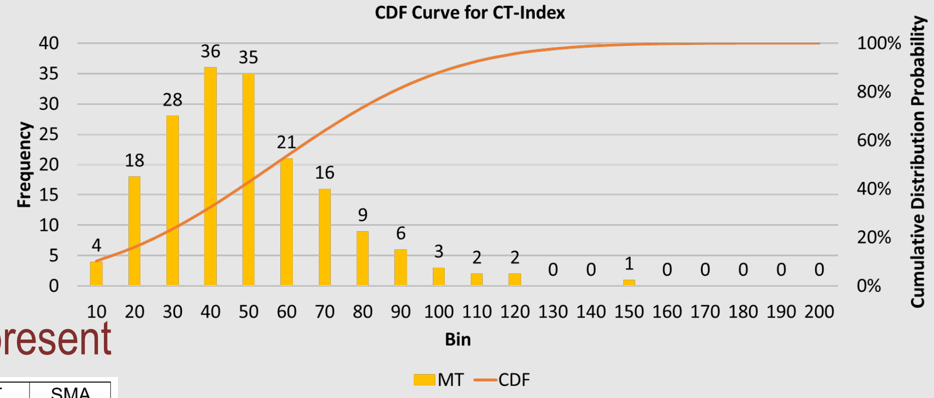
BMD Shadow Projects in WI

- CT-Index cumulative distribution function (CDF) curves

LT



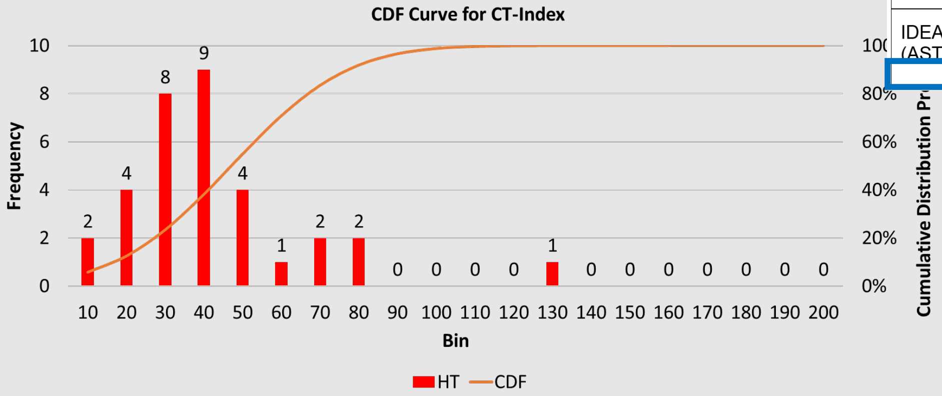
MT



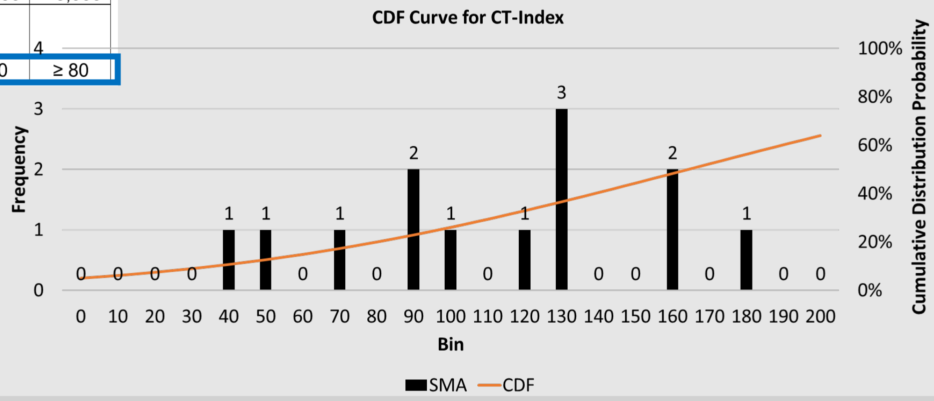
Mix design testing criteria from 2023 to present

Mixture Type	LT	MT	HT	SMA
Hamburg Wheel Tracking (WTM T324) Corrected Rut Depth @ 20,000 Passes (mm) Stripping Number (LC_{SN})	≤ 12.0 ≥ 3,000	≤ 7.5 ≥ 3,000	≤ 5.0 ≥ 3,000	≤ 4.0 ≥ 3,000
IDEAL-CT (ASTM D8225 as modified in CMM 836.6.10.2)				4
CT-Index	≥ 30	≥ 30	≥ 30	≥ 80

HT

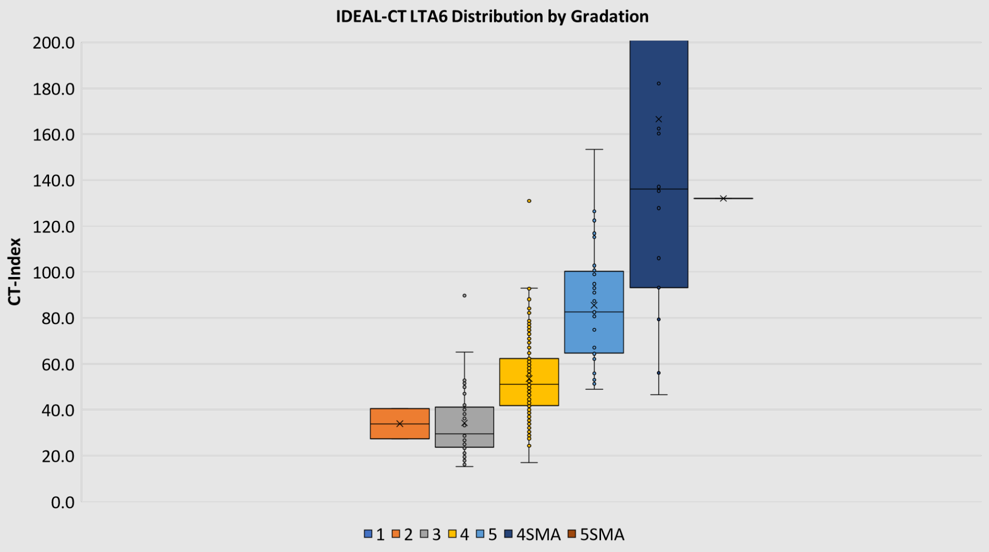


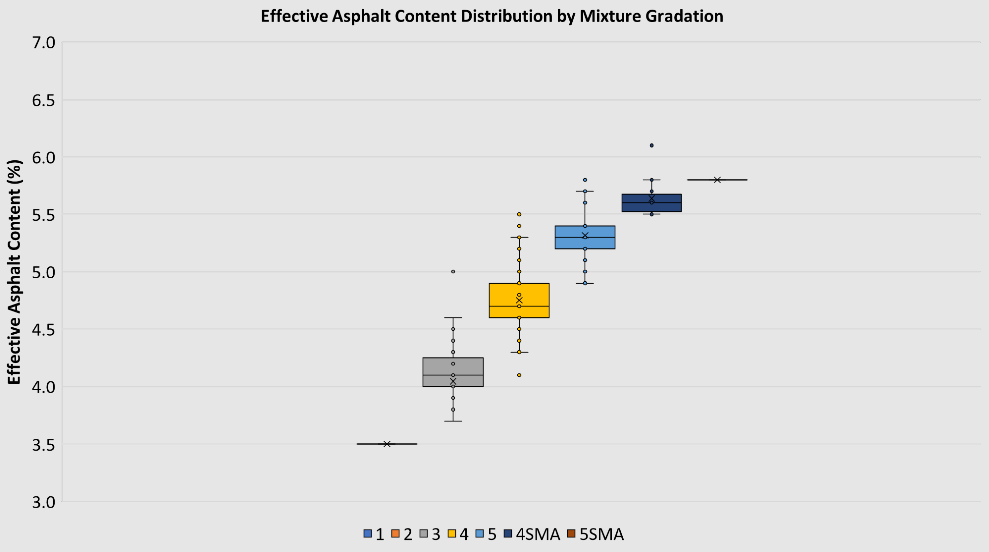
SMA



BMD Shadow Projects in WI

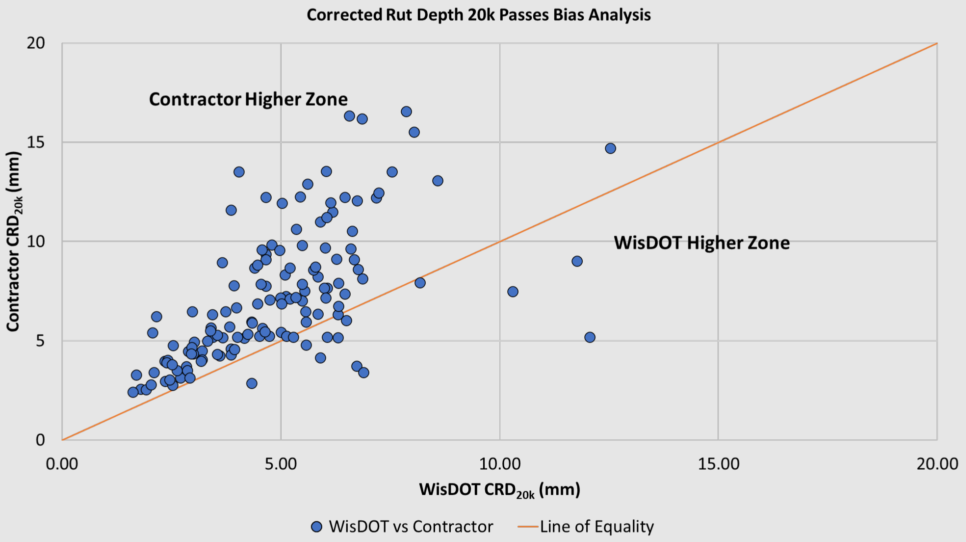
- The influence of aggregate size on cracking resistance performance

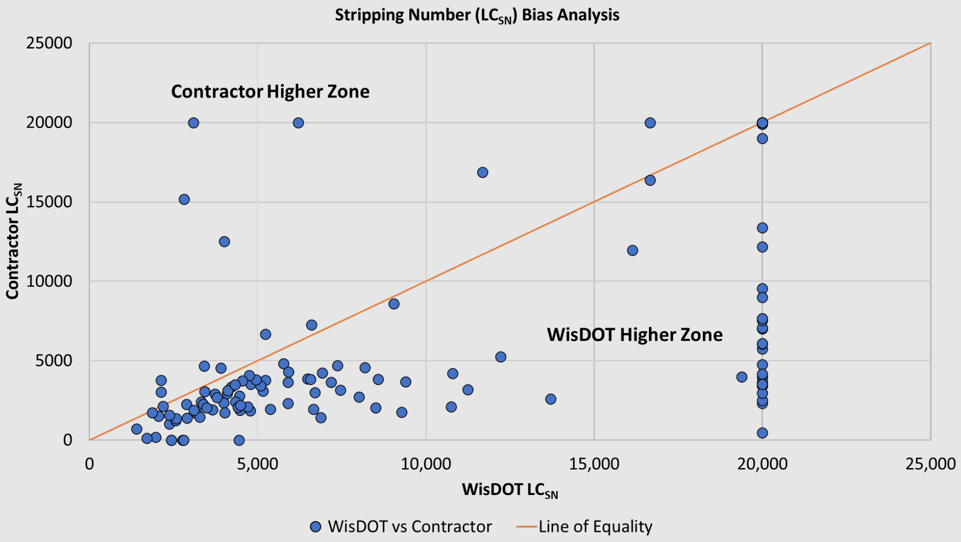




BMD Shadow Projects in WI

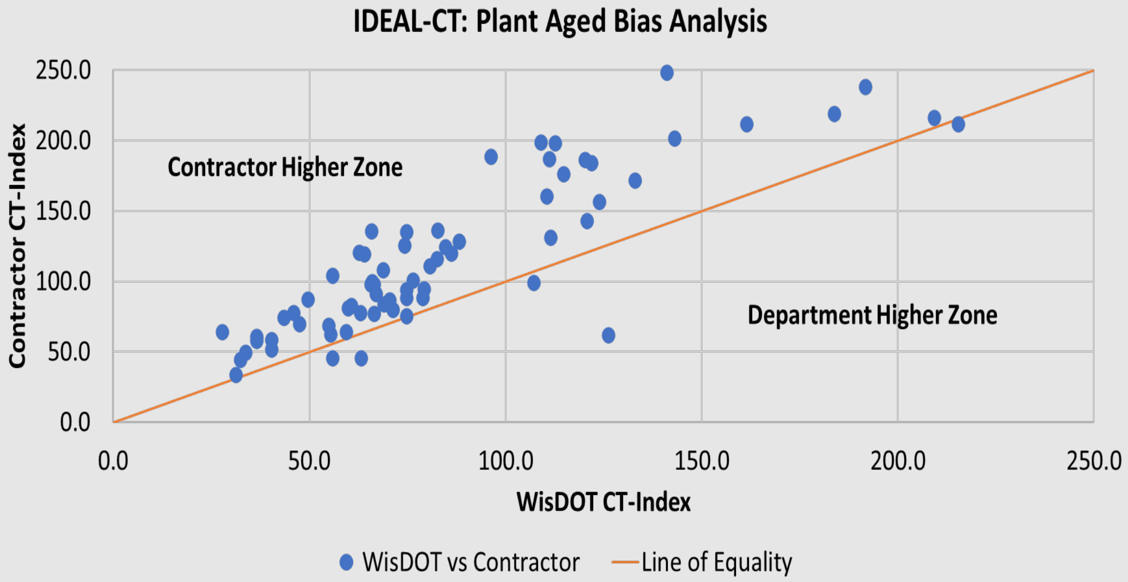
- Bias analysis
  - CRD and SN data

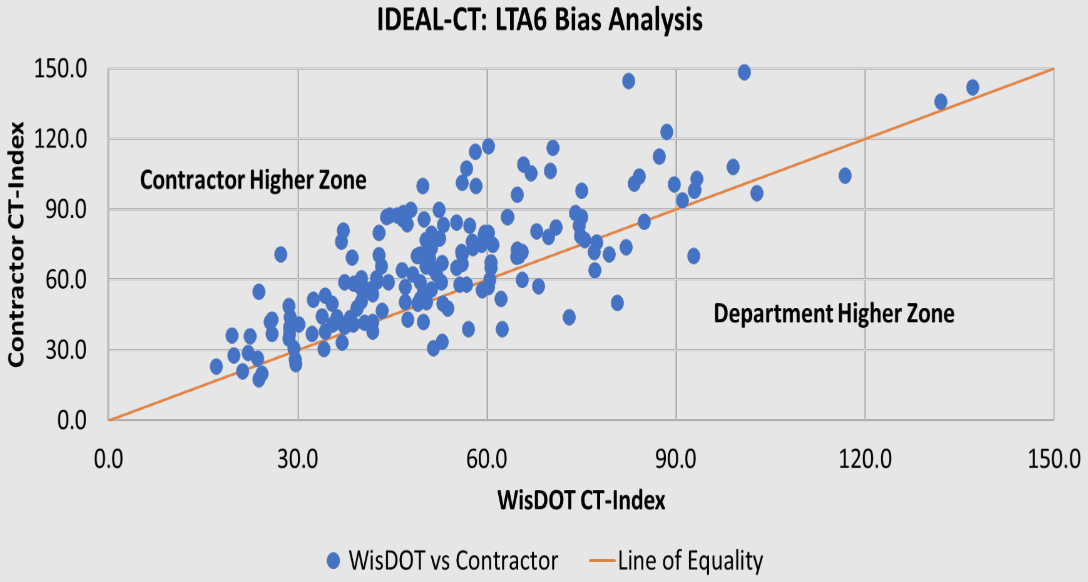




BMD Shadow Projects in WI

- Bias analysis
  - CT-Index data





BMD Shadow Projects in WI

- What does bias analysis data tell us?
  - Results from IDEAL-CT and HWTT indicated that on average, among the 287 mixtures tested, contractor test results exhibited less aging than those from the department
  - Based on these determinations, sample handling, preparation, and testing procedures were scrutinized, and a detailed formal procedure was issued for future performance testing

BMD Shadow Projects in WI

- What was done to decrease the interlaboratory variability?
  - We thought about every single possible scenario ….

BMD Sample Preparation

This aging / conditioning and handling procedure was developed by the WisDOT Bureau of Technical Services HMA Unit to minimize the aging and conditioning influences on the balanced mix design test results.

1. **Reheating:**
   A. Place one box each of IDEAL-CT Plant Aged (PA), IDEAL-CT Long-Term Aged (LTA6), and Hamburg Wheel Test (HWT), unopened, in a preheated oven at 135°C ± 3°C (275°F ± 5°F) for 2 hours ± 5 minutes. Boxes should remain shut for the duration of the reheating procedure.

2. **Splitting:**
   A. Immediately after reheating:
   - Split five, approximately 2,600g*, specimens from the first box: one for a trial puck, and four for IDEAL-CT (PA) pucks. Place the split specimens into small bowls or pans.
   - Split four, approximately 2,600g*, specimens from the second box for the HWT pucks. Place the split specimens into small bowls or pans.
   - Split four, approximately 2,600g*, specimens from the third box for IDEAL-CT (LTA6). Place the specimens in shallow pans (approximately 13" x 9" x 2"). The mix should be ¾" - 1" deep in the pan. Cover the pans with foil and store at room temperature (23 - 25.5°C / 73 - 78°F) to prepare for long-term aging the following day.

   B. Continue to compaction of the trial puck in step 3 below and begin to cool the IDEAL-CT (PA) and HWT specimens to room temperature (23 - 25.5°C / 73 - 78°F) for 2 hours ± 5 minutes in front of a fan.

   **NOTE: The weight of the split specimens will be approximately 2,600 grams to produce pucks that are 61 mm tall at an air void content of 7.0% ± 0.5%. The Gmm 4-point running average corresponding to the mix can be used to estimate the split specimen weights at 7.0% air voids.*

3. **Compaction: Trial, Plant Aged and HWT Pucks**
   A. Compact the trial specimen to a height of 61 mm and 7.0% ± 0.5% air voids at 127°C ± 3°C (261°F ± 5°F). Record the length of time (T) required to compact the specimen to the required height.
   B. Measure the Gmb after the sample has cooled for at least 1 hour in front of a fan. Determine split specimen weight adjustment (W), if needed, to meet the air void target (7.0% ± 0.5%) for the remaining samples to be compacted.
   C. Adjust all specimen batch weights (including the LTA6 specimens) according to the weight adjustment (W) determined in step 3B.
   D. Reheat the IDEAL-CT (PA) and HWT specimens in a preheated oven at 135°C ± 3°C (275°F ± 5°F) for 2 hours ± 5 minutes. Place the specimens in the oven, one specimen at a time; space their placement times by the length of time (T) determined in step 3A. This is to ensure that each specimen is aged the same amount of time while others are being compacted.
   E. Compact remaining specimens at the determined adjusted weights to a height of 61 mm and 7.0% ± 0.5% air voids at 135°C ± 3°C (275°F ± 5°F).
   F. Measure the Gmb after the specimens have cooled for at least 1 hour in front of a fan. Verify the target air void content (7.0% +/- 0.5%) was achieved for all specimens.

4. **Compaction: Long-Term Aged Pucks**
   A. Uncovered pans are placed in a preheated oven for 6 h ± 5 min at a temperature of 135 ± 3°C (275 ± 5°F). Place the specimens in the oven, one specimen at a time; space their placement times by the length of time (T) determined in step 3A. This is to ensure that each specimen is aged the same amount of time while others are being compacted.
   B. After the 6-hour aging, compact specimens at the determined adjusted weights to a height of 61 mm and 7.0% ± 0.5% air voids at 135°C ± 3°C (275°F ± 5°F).
   C. Measure the Gmb after the sample has cooled for at least 1 hour in front of a fan. Verify that target air void content (7.0% +/- 0.5%) was achieved for all specimens.

5. **Testing**
   A. Hamburg Wheel Test (AASHTO T324 as modified below)
      i. Test temperature is 46°C ± 1°C (115°F ± 2°F).
      ii. Test until 20,000 passes or 12.5-mm rut depth.
   B. IDEAL-CT (ASTM D8225 as modified below)
      i. Condition samples in water bath at 25°C ± 1°C for 2 hours ± 10 minutes.

BMD Shadow Projects in WI

- Round Robin Study results

$$Z = \frac{x_i - \bar{x}}{\sigma_s}$$

$$d2s = 2\sigma_s\sqrt{2}$$

	Lab	IDEAL-CT		Hamburg Wheel Test						
		Planted Aged	LTA-6	Rut Depth	Passes to Failure	SIP	CRD 10k	CRD 20k	LCSN	LCST
	Lab 1	92.5	69.8	9.21	20,000	14,401	4.15	5.12	6,952	23,743
	Lab 2	91.2	60.9	5.71	20,000	#N/A	4.11	5.39	20,000	#N/A
	Lab 3	109.7	87.1	8.20	20,000	#N/A	5.13	6.67	17,000	#N/A
	Lab 4	72.8	67.8	5.52	20,000	#N/A	4.46	5.46	20,000	#N/A
Statistics	Average:	91.6	71.4	7.2	20,000.0	#N/A	4.5	5.7	15,988.0	#N/A
	Median:	91.9	68.8	7.0	20,000.0	#N/A	4.3	5.4	18,500.0	#N/A
	Samp Std. Dev:	15.08	11.14	1.83	0.00	#N/A	0.47	0.69	6187.78	#N/A
	COV:	16.5%	15.6%	25.6%	0.0%	#N/A	10.6%	12.2%	38.7%	#N/A
Z-Scores	Z-Score Lab 1:	0.06	-0.14	1.12	#N/A	#N/A	-0.66	-0.78	-1.46	#N/A
	Z-Score Lab 2:	-0.02	-0.94	-0.79	#N/A	#N/A	-0.75	-0.39	0.65	#N/A
	Z-Score Lab 3:	1.20	1.41	0.57	#N/A	#N/A	1.42	1.47	0.16	#N/A
	Z-Score Lab 4:	-1.24	-0.32	-0.89	#N/A	#N/A	-0.01	-0.29	0.65	#N/A
Quartiles	IQR:	10.2	8.1	2.8	0	#N/A	0.49	0.44	5,512.0	#N/A
	Q1:	86.6	66.1	5.7	20,000	#N/A	4.14	5.32	14,488.0	#N/A
	Q3:	96.8	74.1	8.5	20,000	#N/A	4.63	5.76	20,000.0	#N/A
	Low Range:	71.3	54.0	1.5	20,000	#N/A	3.41	4.66	6220	#N/A
	High Range:	112.1	86.2	12.6	20,000	#N/A	5.36	6.42	28268	#N/A
	d2s:	42.6	31.5	5.2	0.0	#N/A	1.3	1.9	17,501.7	#N/A

Any questions or comments?

Thank You!