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Impact of Replicate Size on IDEAL-CT in Asphalt Mixtures

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NESMEA – October 29th, 2025


Source: Getty Images

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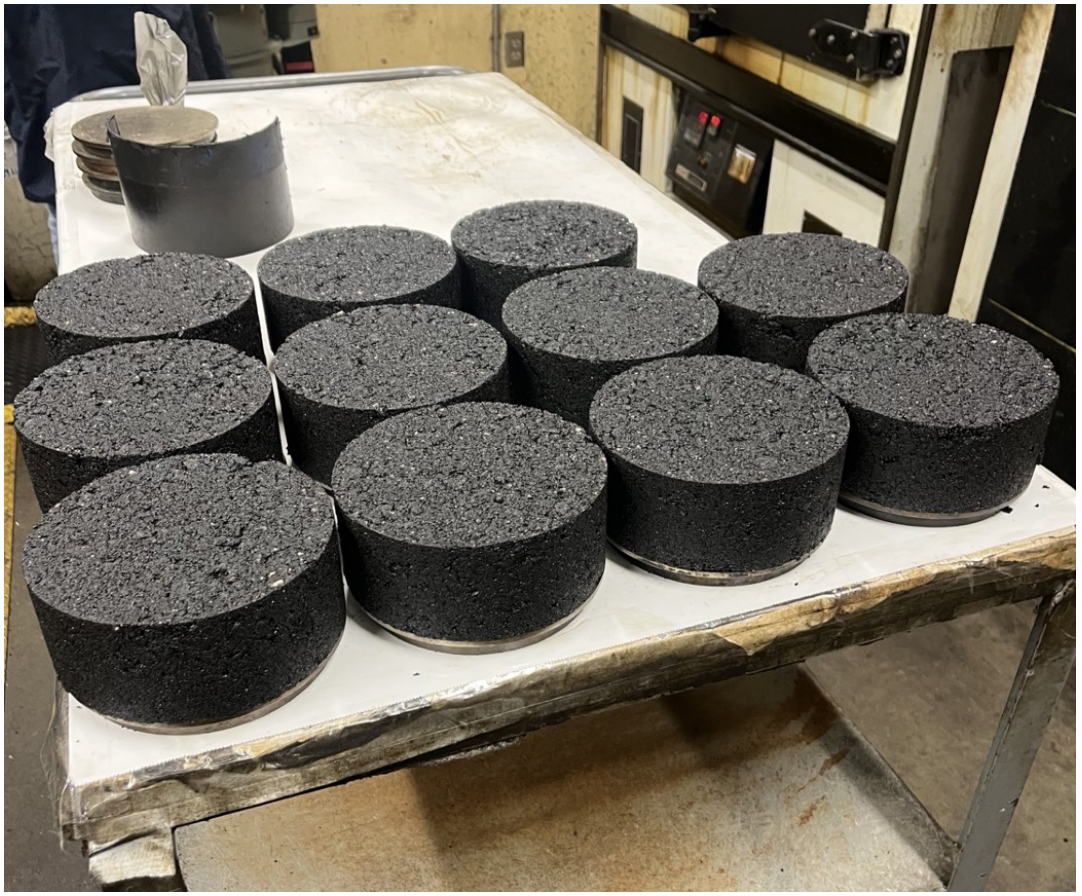
Questions:

Why do we test replicates?

How do we determine how many replicates to test?



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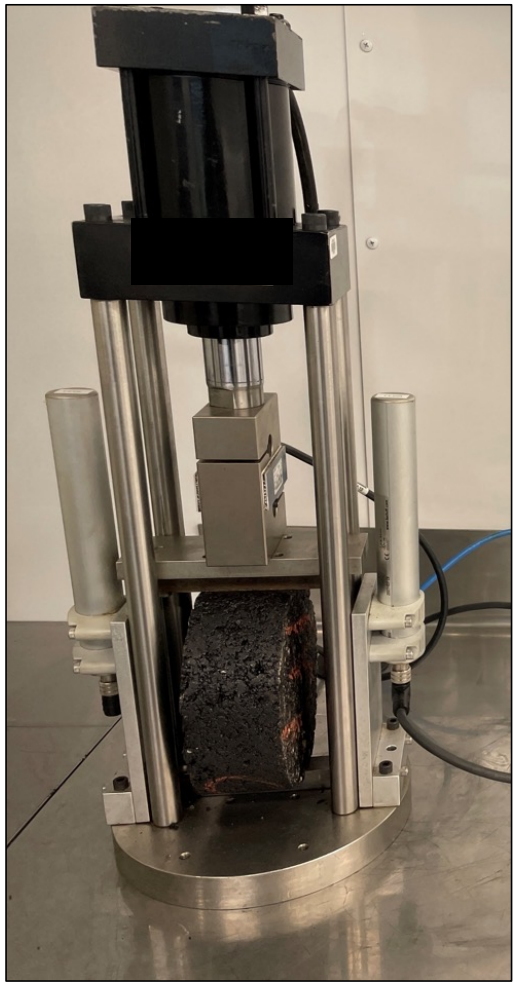
Objective

- Measure the impact of replication on the accuracy and precision of Balanced Mix Design testing.
- How accurate is the estimation of the true mean and true standard deviation when using a small number of replicates?
- Do larger sample sizes (e.g., 10 or 15 replicates) reduce the variability and error in the test results, leading to more reliable and consistent estimates of the true values?



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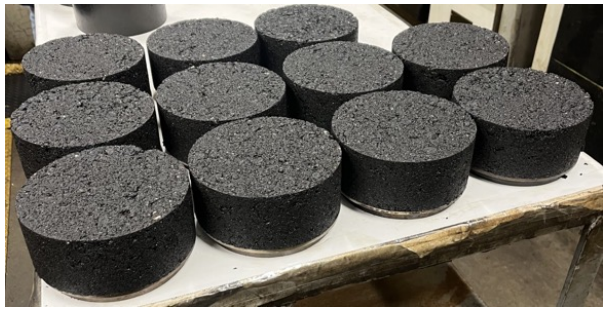
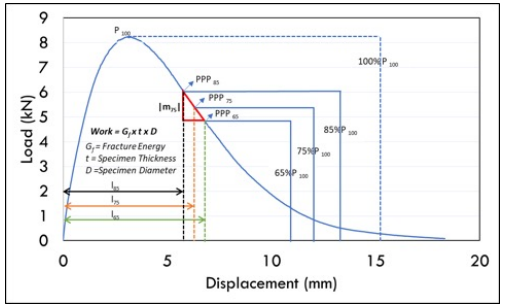
Study Basics / Overview

Sample mixture

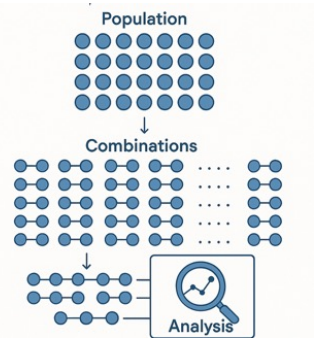


Fabricate 30+ replicates



Perform IDEAL-CT

Analyze all combinations from given replicate size



** Results from 30+ replicates assumed to reflect population*

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Specimen Fabrication Notes

- All testing performed on reheated plant produced mixtures
  - Mini-stockpile sampling at the plant
  - Followed consistent plant-mix procedure (135°C × 3 h per state protocol); applied uniformly across all mixes.
- All replicates fabricated and tested by same two MATC technicians and single load frame
- Lag time held constant for all replicates for a given mixture.
- All replicates tested within 48 hours of fabrication – allowed to cool fully before testing

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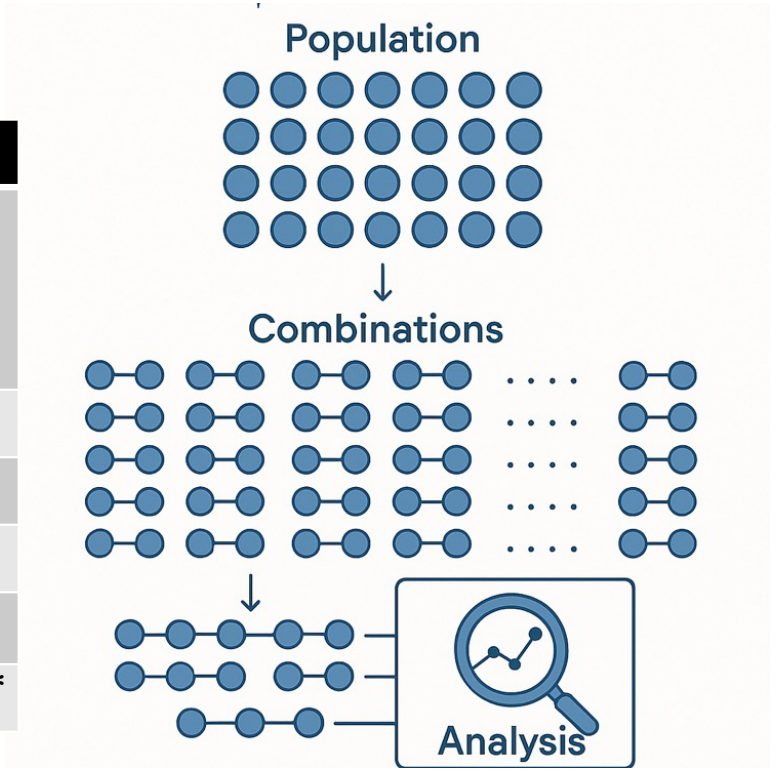
Mixture Properties

Mixture Property	Wisconsin Mixture	Iowa Mixture	Maine Mixture
Percent Passing ¾" Sieve	100	100	
Percent Passing ½" Sieve	96	95	
Percent Passing 3/8" Sieve	88	89	
Percent Passing #4 Sieve	71	64	
Percent Passing #8 Sieve	55	44	
Percent Passing #16 Sieve	43	31	
Percent Passing #30 Sieve	31	19	
Percent Passing #50 Sieve	14	9	
Percent Passing #100 Sieve	7	5	
Percent Passing #200 Sieve	4.8	3.8	
Design Gyrations	75	75	
Design Air Voids	3.0%	4.0%	
Design Asphalt Content	5.8%	5.2%	
Asphalt Binder Grade	PG58-28	PG58H-28	
Voids in the Mineral Aggregate (VMA)	15.1%	14.6%	
Percent Reclaimed Asphalt Pavement	25.0%	18.0%	

Analysis Methodology

Sample Size (n)	Total Possible Combinations		
	Wisconsin Mixture (N = 30)	Iowa Mixture (N = 32)	Maine Mixture (N = 34)
3	4,060	4,960	5,984
4	27,405	35,960	46,376
5	142,506	201,376	278,256
10	30,045,015	64,512,240	131,128,140
15	155,117,520	565,722,720*	1,855,967,520*

* Analysis for this situation was not performed due to the computation challenges with the high number of unique combinations.



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Data Generated

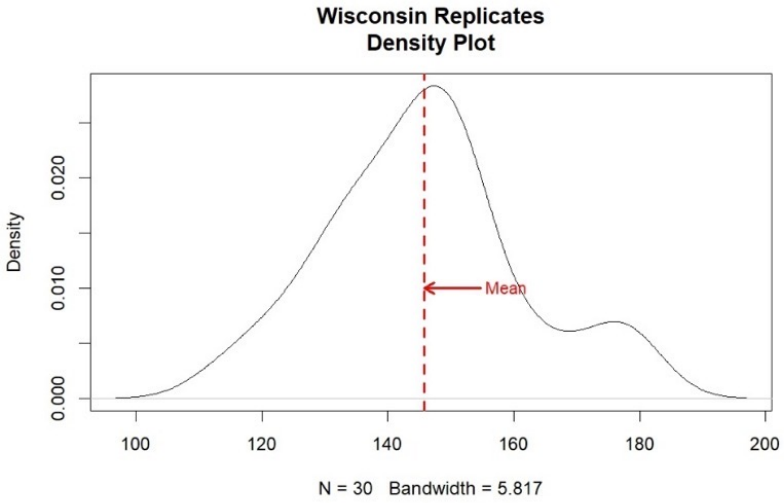
CT_{index}

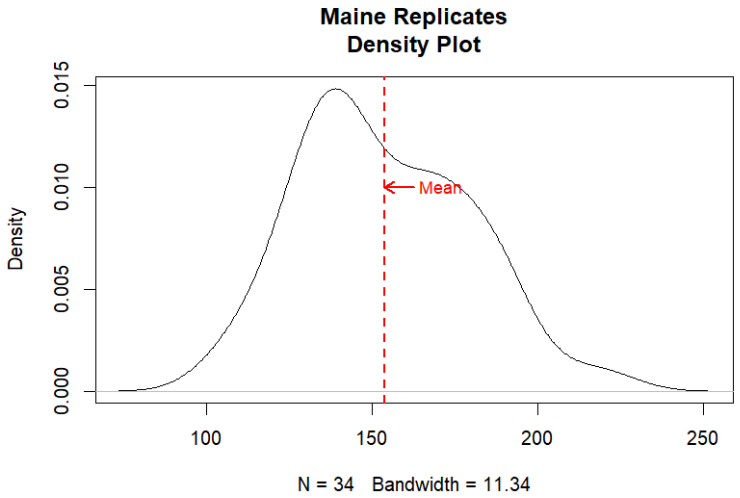
Summary	Wisconsin Mixture	Iowa Mixture	Maine Mixture
Average	145.8	147.4	153.7
Standard Deviation	15.8	27.3	25.5
COV	10.8%	18.5%	16.6%

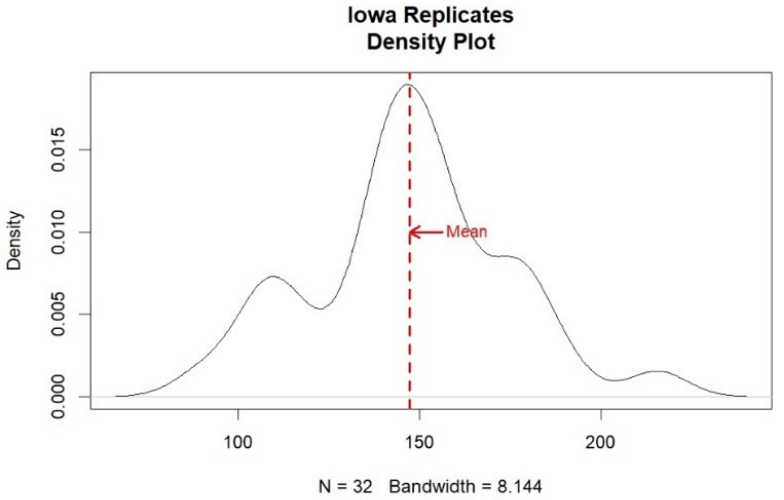
Replicate Number	Wisconsin Mixture	Iowa Mixture	Maine Mixture
1	114.2	90.7	107.7
2	120.6	105.1	112.0
3	124.2	106.7	122.4
4	127.4	106.9	124.7
5	131.1	112.6	129.5
6	133.0	115.5	131.0
7	133.4	123.6	133.3
8	133.8	136.2	133.3
9	136.7	136.6	134.2
10	138.5	138.2	135.8
11	141.4	140.5	135.9
12	141.6	141.2	139.5
13	142.0	142.3	141.6
14	144.0	144.5	142.4
15	146.5	145.6	143.0
16	146.5	146.0	144.0
17	147.4	148.3	145.9
18	148.0	148.5	148.3
19	149.7	151.6	152.0
20	150.8	152.0	160.3
21	151.3	155.5	163.1
22	151.4	155.9	163.2
23	151.7	157.0	164.2
24	154.5	159.6	168.1
25	155.2	164.2	169.8
26	161.7	173.1	170.6
27	165.9	174.0	174.6
28	174.5	178.3	178.0
29	177.5	179.4	184.7
30	179.5	180.6	186.5
31	NA	190.0	187.2
32	NA	215.6	188.1
33	NA	NA	192.4
34	NA	NA	217.8

Normality Assessment

- Slight departures were observed in the distribution tails
- Combined statistical (skewness, kurtosis, Shapiro-Wilk) and graphical (density plot, Q-Q plot) evidence supports the assumption of normality for replicate datasets.







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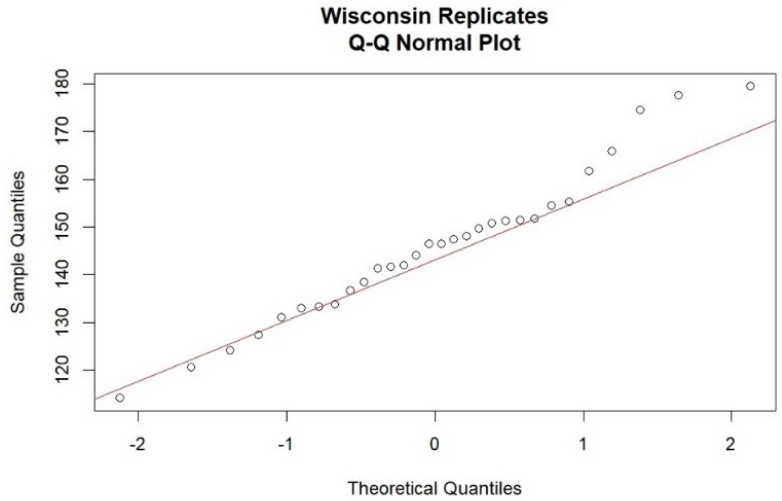

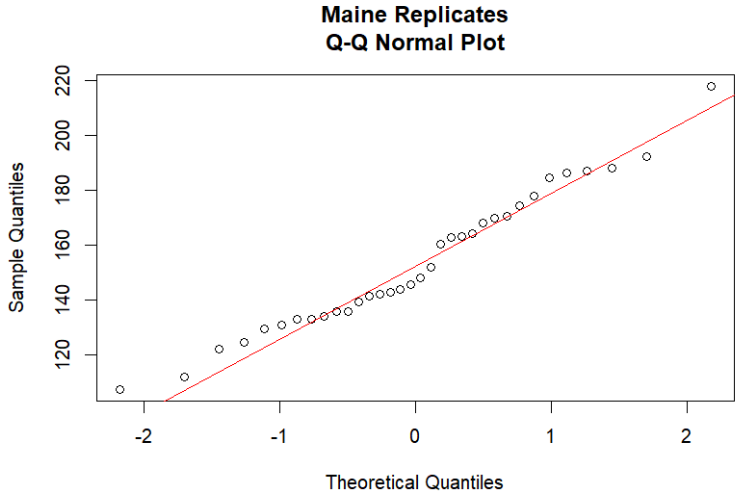

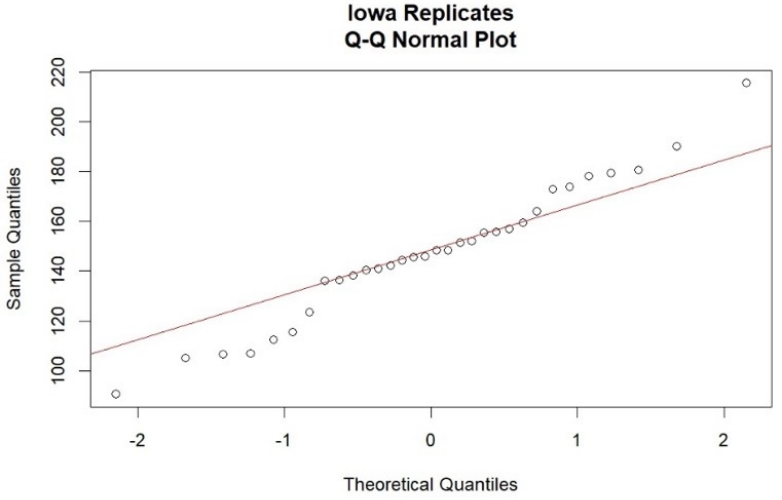

Analysis Methodology - Terminology

- **Average Error:** Average error from the true measure over all combinations.
- **Probability of Error:** Percent of combinations exceeding that error (10% or 15%).
- **Bias:** Difference between average of all combinations and true population.

What does a 10% or 15% error look like?

10% Error

True population: $CT_{index} = 100$ (COV = 20%)

Measurement A: $CT_{index} = 90$ (COV = 18%)

Measurement B: $CT_{index} = 110$ (COV = 22%)

15% Error

True population: $CT_{index} = 100$ (COV = 20%)

Measurement A: $CT_{index} = 85$ (COV = 17%)

Measurement B: $CT_{index} = 115$ (COV = 23%)

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Means Summary

- As replicate size increases, average error decreases
- As population COV increases errors decrease
- Significant reduction in errors from n=3 to n=5
- No bias observed as expected

Sample Size (n)	Average Mean Error	Probability of Mean Error		Mean Bias
		>10%	>15%	
Wisconsin Mixture (Population COV = 10.8%)				
3	4.8%	8.9%	1.0%	0.0%
4	4.1%	4.6%	0.2%	0.0%
5	3.6%	2.1%	0.0%	0.0%
10	2.3%	0.0%	0.0%	0.0%
15	1.6%	0.0%	0.0%	0.0%
Iowa Mixture (Population COV = 18.5%)				
3	8.2%	32.5%	14.5%	0.0%
4	7.0%	25.4%	8.5%	0.0%
5	6.1%	19.3%	4.8%	0.0%
10	3.9%	3.8%	0.1%	0.0%
15	NA	NA	NA	NA
Maine Mixture (Population COV = 16.6%)				
3	7.4%	28.3%	10.3%	0.0%
4	6.3%	20.6%	5.3%	0.0%
5	5.5%	14.8%	2.6%	0.0%
10	3.5%	2.1%	0.0%	0.0%
15	NA	NA	NA	NA

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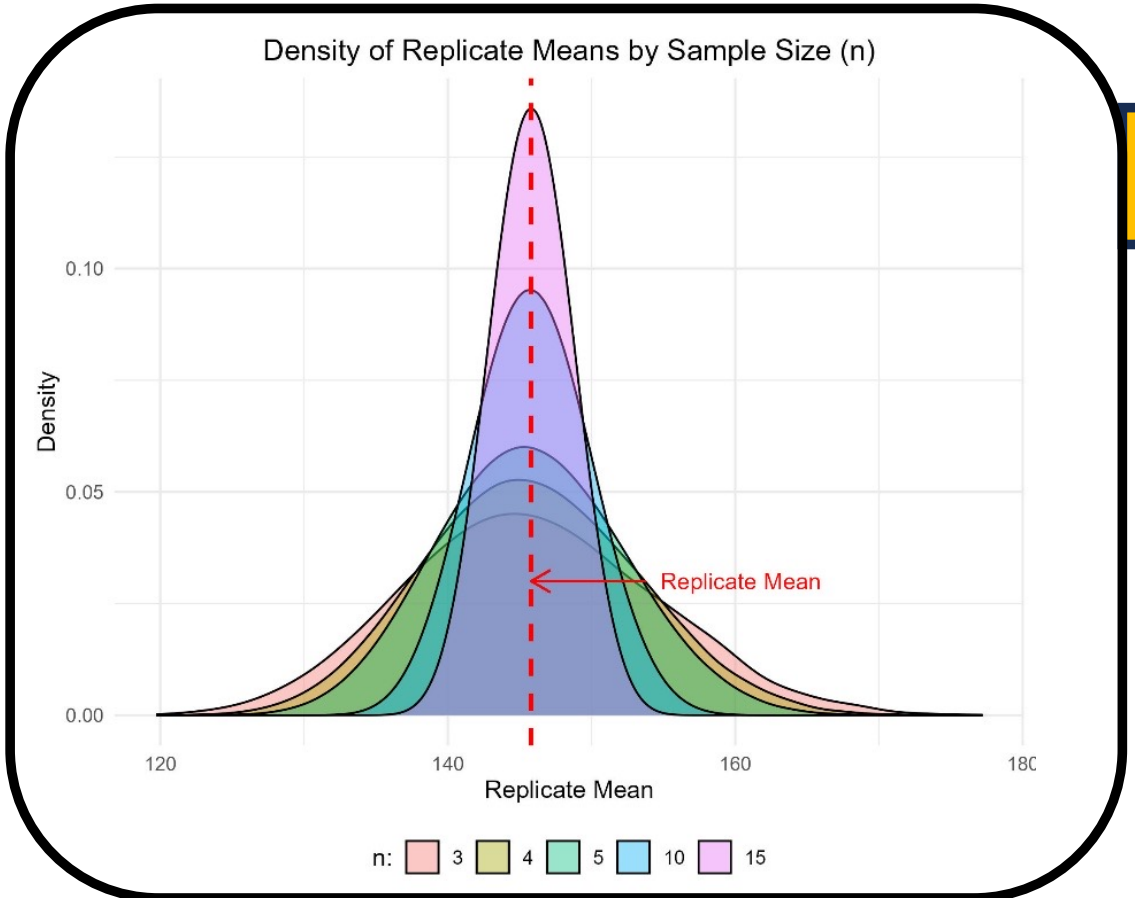
Means – Density Plots



Wisconsin Mixture

Iowa Mixture

Maine Mixture

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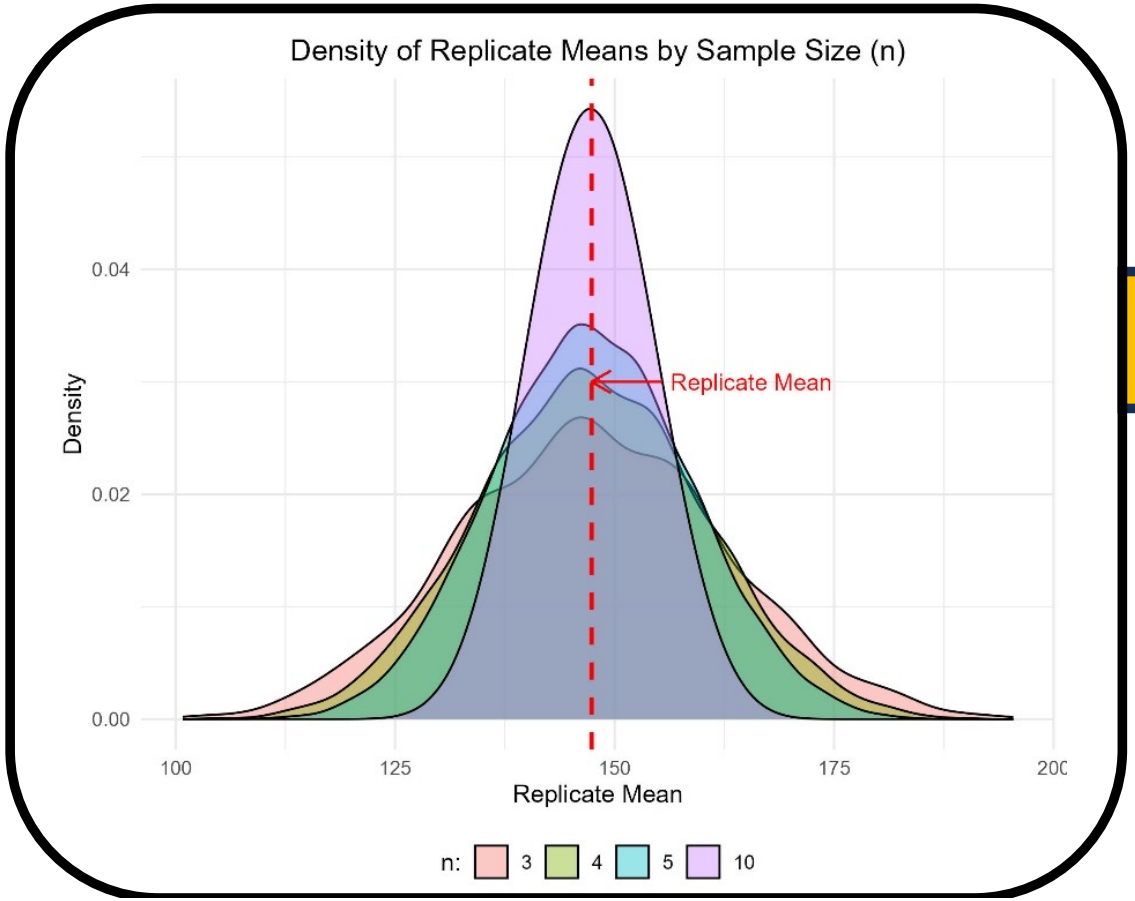
Means – Density Plots



Wisconsin Mixture

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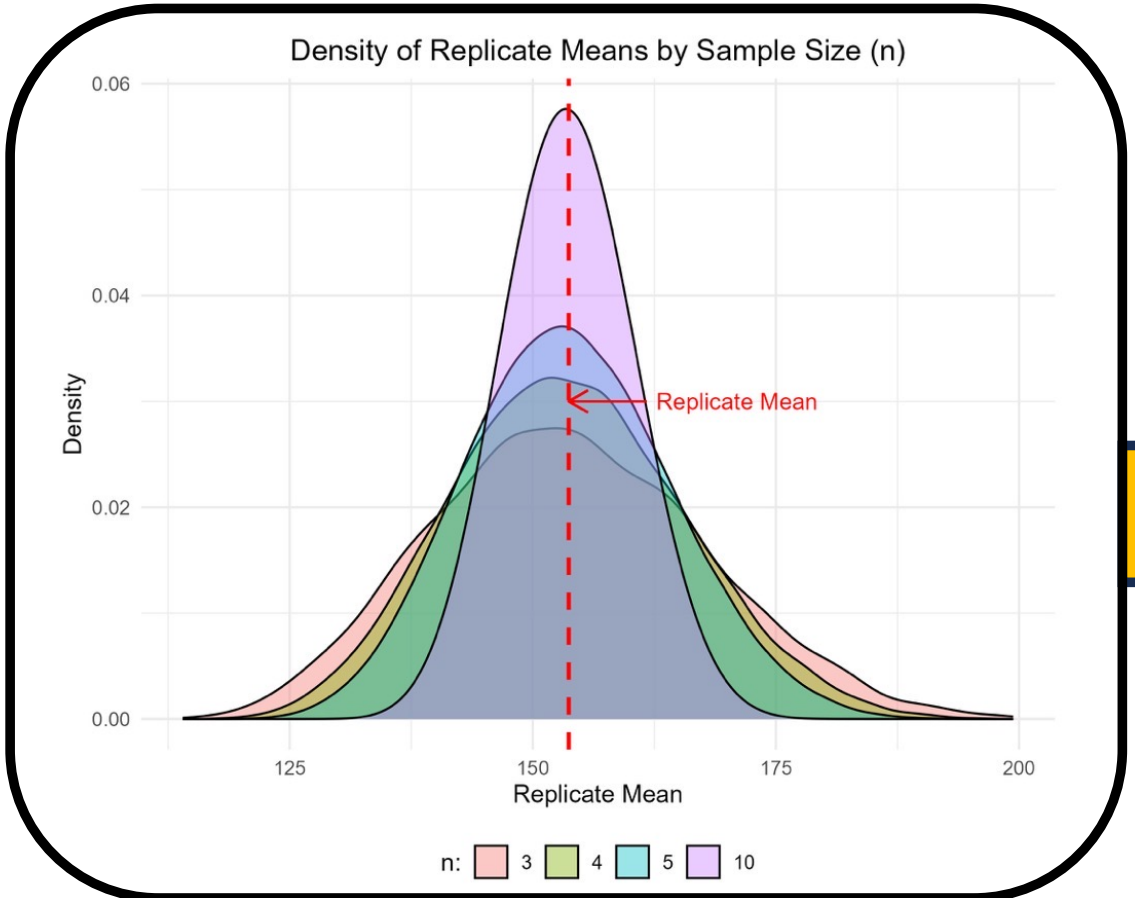
Means – Density Plots



Wisconsin Mixture

Iowa Mixture

Maine Mixture

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Standard Deviation Summary

- Error reduction trend stable across mixtures with different population COV
- Moving from 3 to 5 replicates reduced standard deviation bias by 50%
- Negative bias observed (↓ = underestimates variability

Sample Size (n)	Average Standard Deviation Error	Probability of Standard Deviation Error		Standard Deviation Bias
		>10%	>15%	
Wisconsin Mixture (Population COV = 10.8%)				
3	39.7%	85.3%	78.1%	-11.3%
4	32.5%	82.1%	73.1%	-7.7%
5	27.8%	78.3%	68.3%	-5.7%
10	16.3%	62.8%	46.4%	-2.1%
15	11.1%	47.3%	28.3%	-1.0%
Iowa Mixture (Population COV = 18.5%)				
3	39.6%	86.7%	81.0%	-11.3%
4	32.3%	83.4%	73.2%	-7.7%
5	27.5%	76.9%	66.2%	-5.6%
10	16.9%	64.8%	48.9%	-2.0%
15	NA	NA	NA	NA
Maine Mixture (Population COV = 16.6%)				
3	36.3%	83.4%	74.2%	-10.0%
4	28.8%	76.3%	66.3%	-6.5%
5	24.6%	74.7%	62.7%	-4.7%
10	15.2%	62.4%	45.3%	-1.7%
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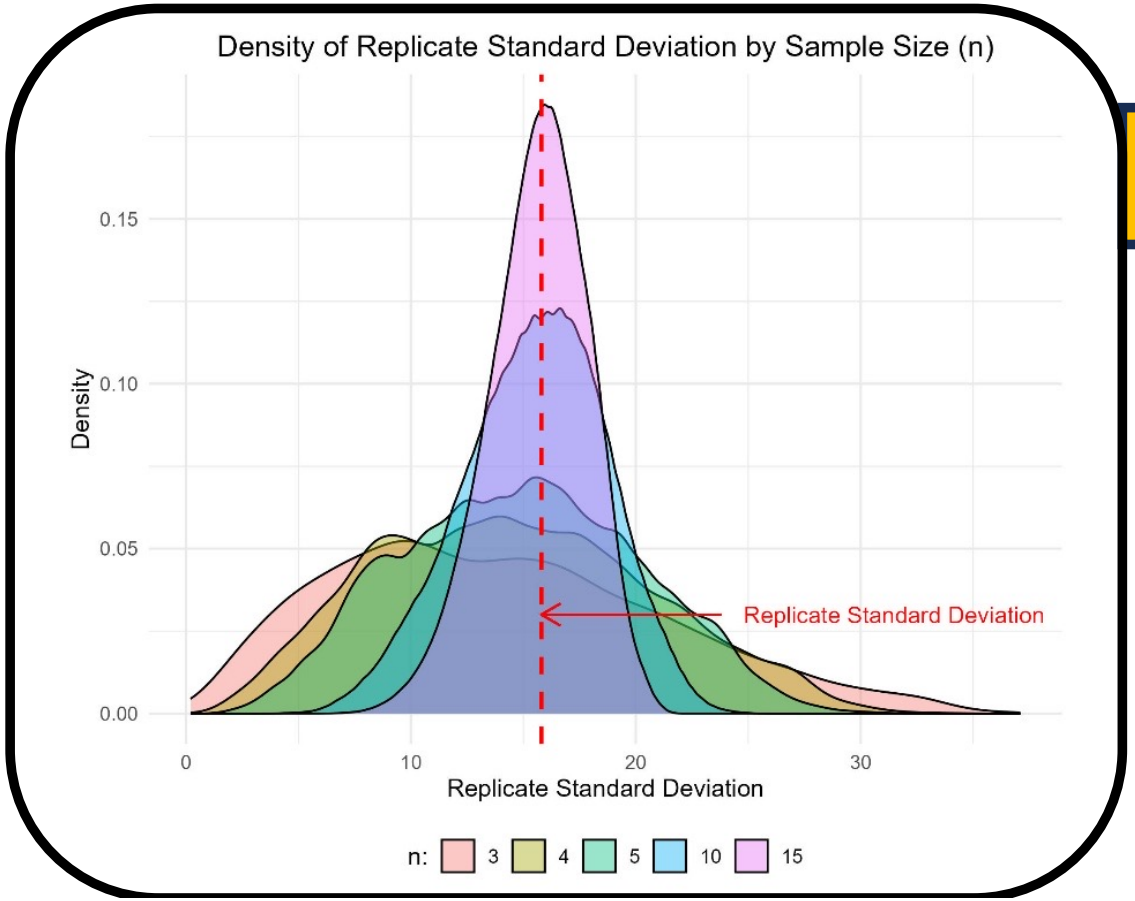
Standard Deviation – Density Plots



Wisconsin Mixture

Iowa Mixture

Maine Mixture

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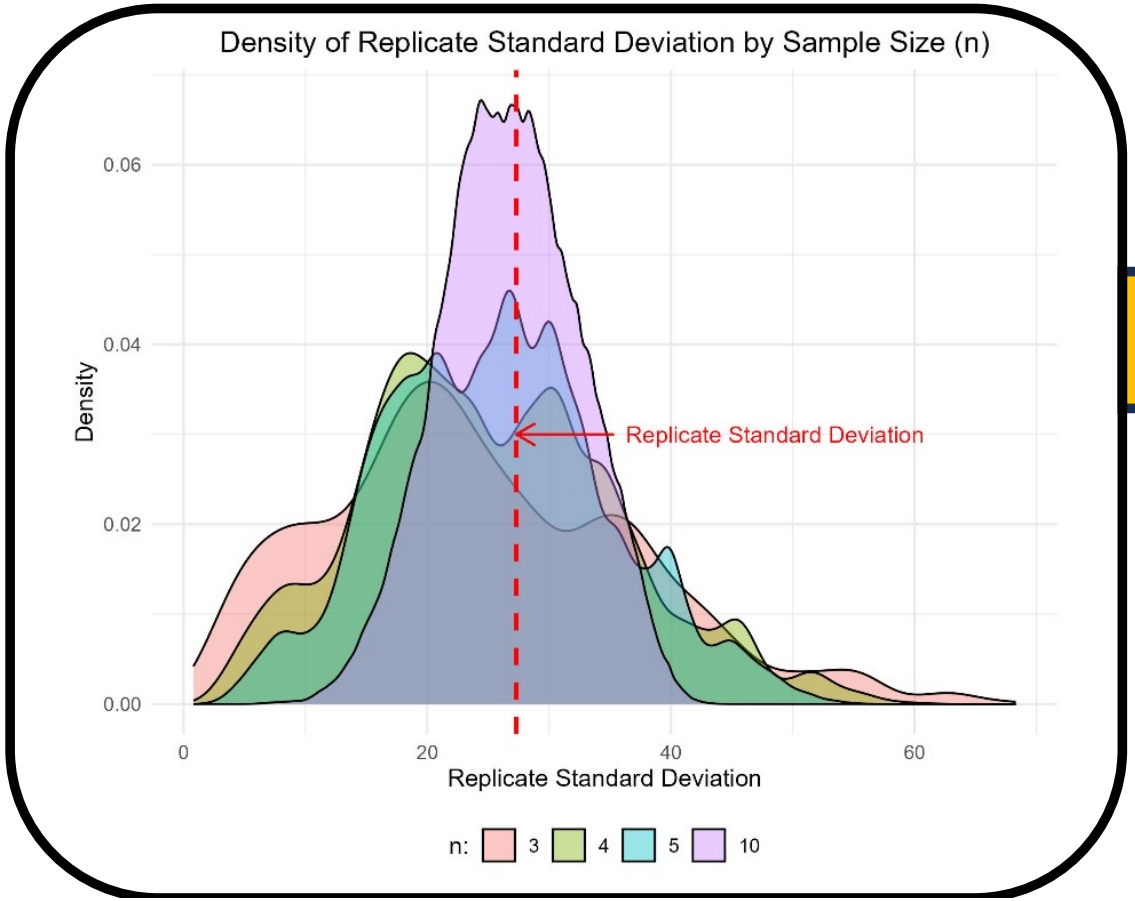
Standard Deviation – Density Plots



Wisconsin Mixture

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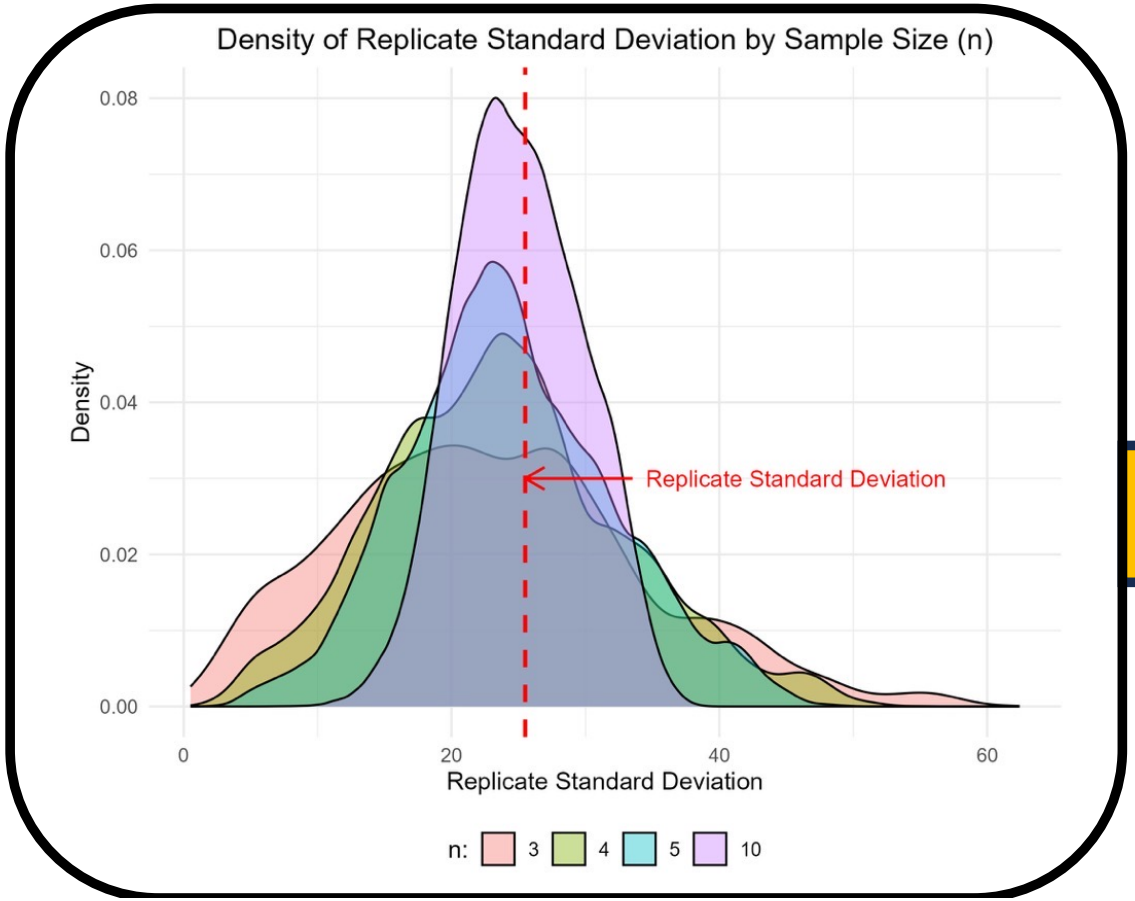
Standard Deviation – Density Plots



Wisconsin Mixture

Iowa Mixture

Maine Mixture

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Gaps

- Variability observed from multiple sources
  - Sampling, splitting, specimen fabrication, testing
- More mixtures with different CT_{index} values needed
  - Look at effects of mix type (fine versus coarse, binder grade, etc.)
- Lacking added inter-lab, inter-operator input

Findings and Conclusions

- Smaller sample sizes (e.g., $n = 5$) showed relatively low error rates for mean estimation.
  - Variability differences between mixtures was evident in the data.
- Smaller sample sizes led to substantially higher error probabilities across all mixtures for standard deviation.
  - Little variability in errors between mixtures.
  - Less replication can underestimate true variability

Results reinforce the importance of using adequate replication in mechanical testing to capture mean and variance.

Implications for Quality Assurance use of BMD

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SPREADING ASPHALT PAVEMENT TECHNOLOGY INNOVATION

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