Variability of RAP

Myths, Mistakes, and
Bad Assumptions

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

Variability of RAP
True or False?

- RAP is more variable than virgin aggregate.
- Fractionation will reduce the variability of RAP stockpiles
- Single source RAP is more consistent than processed RAP from GOK piles

RAP Consistency Data

(Kallas, FHWA, June 1984)

	n	% Pass 2.36 mm		% Pass 75 µm		Asphalt Content	
		Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
California	5	69	6.5	11.8	0.34	5.2	0.04
North Carolina	5	72	0.9	8.0	0.11	5.7	0.11
Utah	10	58	2.8	9.9	1.15	6.2	0.44
Virginia	6	52	1.1	13.0	0.30	5.2	0.12

RAP Consistency Data

Georgia RAP Stockpiles (Kandhal et. al. Sept. 1997)

	n	% Pass 2.36 mm		% Pass 75 µm		Asphalt Content	
		Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
Newton County	10	47.5	4.95	7.14	0.74	5.52	0.23
Forest Pk. mlgs.	5	3.60*	3.41	7.02	1.08	5.46	0.31
Resaca	10	36.4	2.20	8.72	1.36	5.08	0.21
Bryan County	10	42.9	4.63	4.75	0.71	4.83	0.42
Lowndes County	10	49.3	4.82	7.36	0.75	5.60	0.48
Spartan Asphalt	70	58.1	3.5	9.0	0.82	3.8	0.30

RAP QC Statistics from NCAT On-line Survey

RAP property	n	Average (%)	Standard Deviation (%)	
			Average	Range
Asphalt Content	70	5.0	0.46	0.1 to 1.5
% Passing Median Sieve	58	51.7	4.32	0.78 to 9.0
% Passing 75 micron Sieve	58	7.37	1.09	0.3 to 3.0

RAP QC Statistics

Recycled Hot-Mix Asphalt Concrete in Florida: A Variability Study
ICAR – 401-1/98

RAP property	n	Average (%)	Standard Deviation (%)	
			Average	Range
Asphalt Content	20	5.4	0.30	0.1 to .55
% Passing Median Sieve	20	47.9	3.11	1.29 to 5.66
% Passing 75 micron Sieve	20	9.1	0.93	0.45 to 2.22

Data from p.7 & 8

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

ICAR-401-1/98
Recycled Hot-Mix Asphalt Concrete

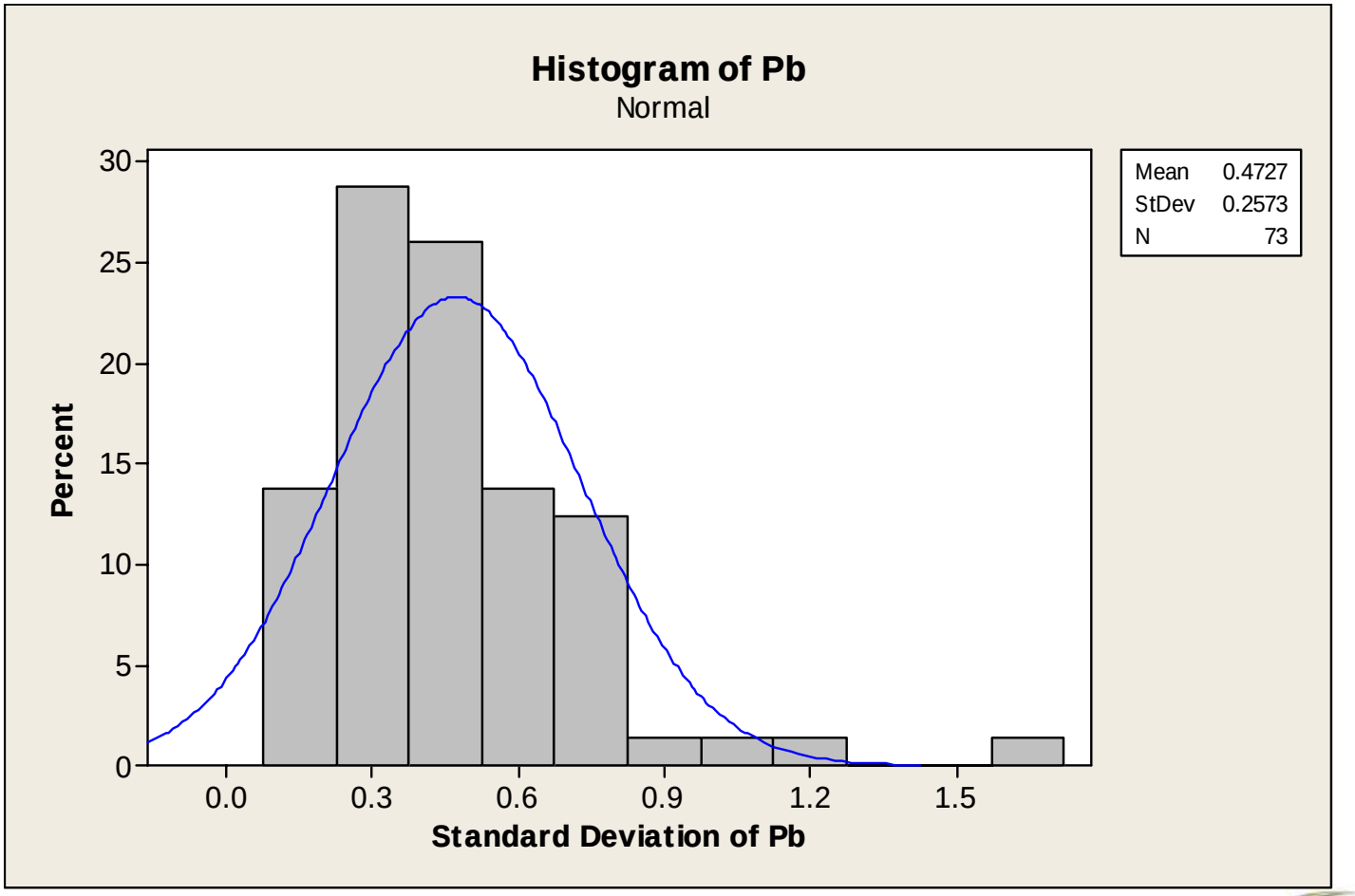
- The statistical analysis revealed that increasing the percentage of RAP does not increase the coefficient of variation of the mix. (This is in the RAP range of 15 to 40% and most of the mixes had between 25-35 percent RAP).
- Based on stockpiles at contractors plant site…
- Analysis of variance on the median coefficient of variation revealed that RAP had a lower variation than virgin aggregates
- ANOVA for the maximum CV indicated that no significant difference between any of the materials: HMAC, RAP, or virgin aggregate.

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

More Information on RAP Variability Statistics

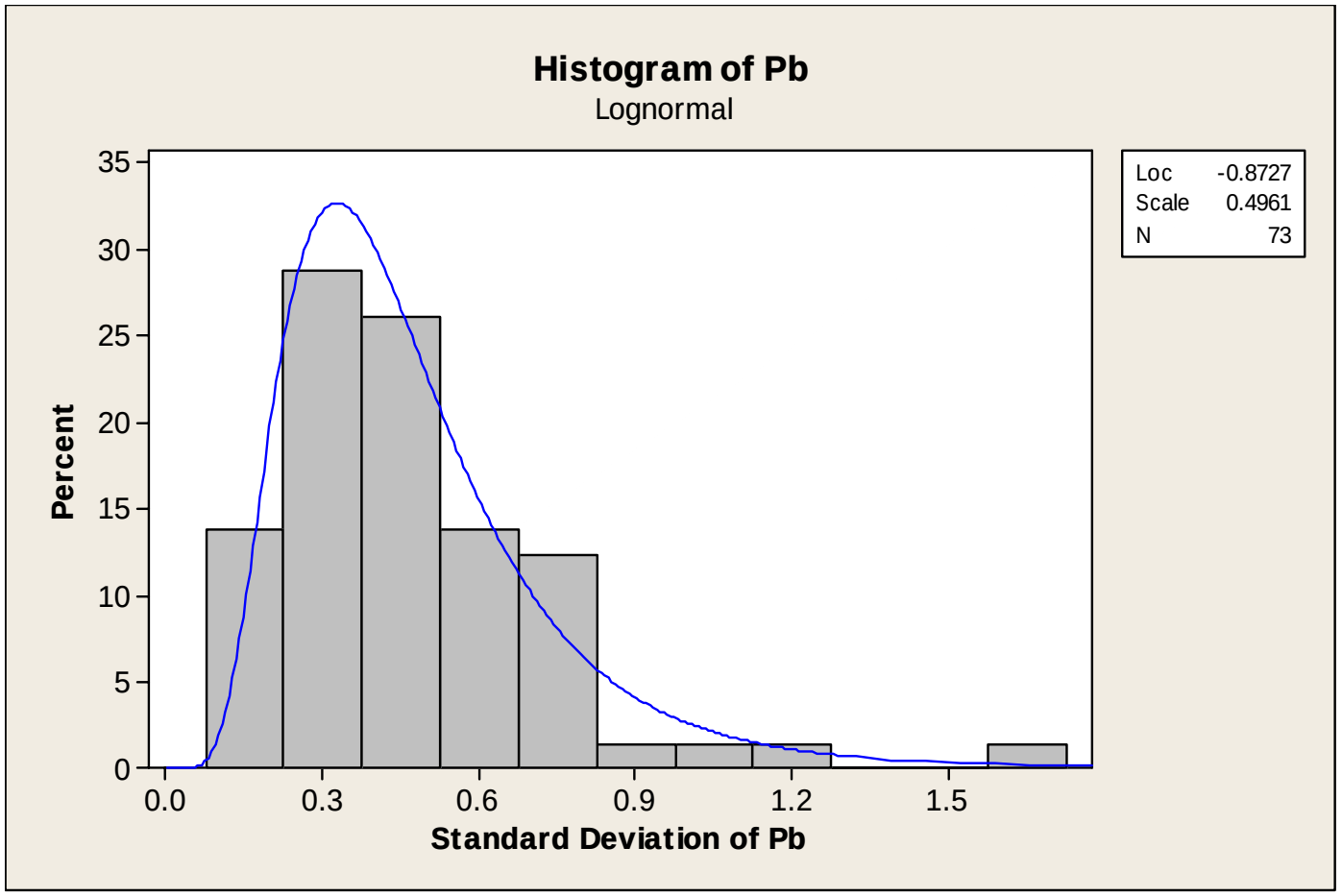
- Asked for data from about 20 contractors across the U.S.
- Compiled data for fractionated and non-fractionated stockpiles
- Received data for over 100 stockpiles
- Some data was not used (n<10 samples)

Variability of Asphalt Content Non-Fractionated Stockpiles



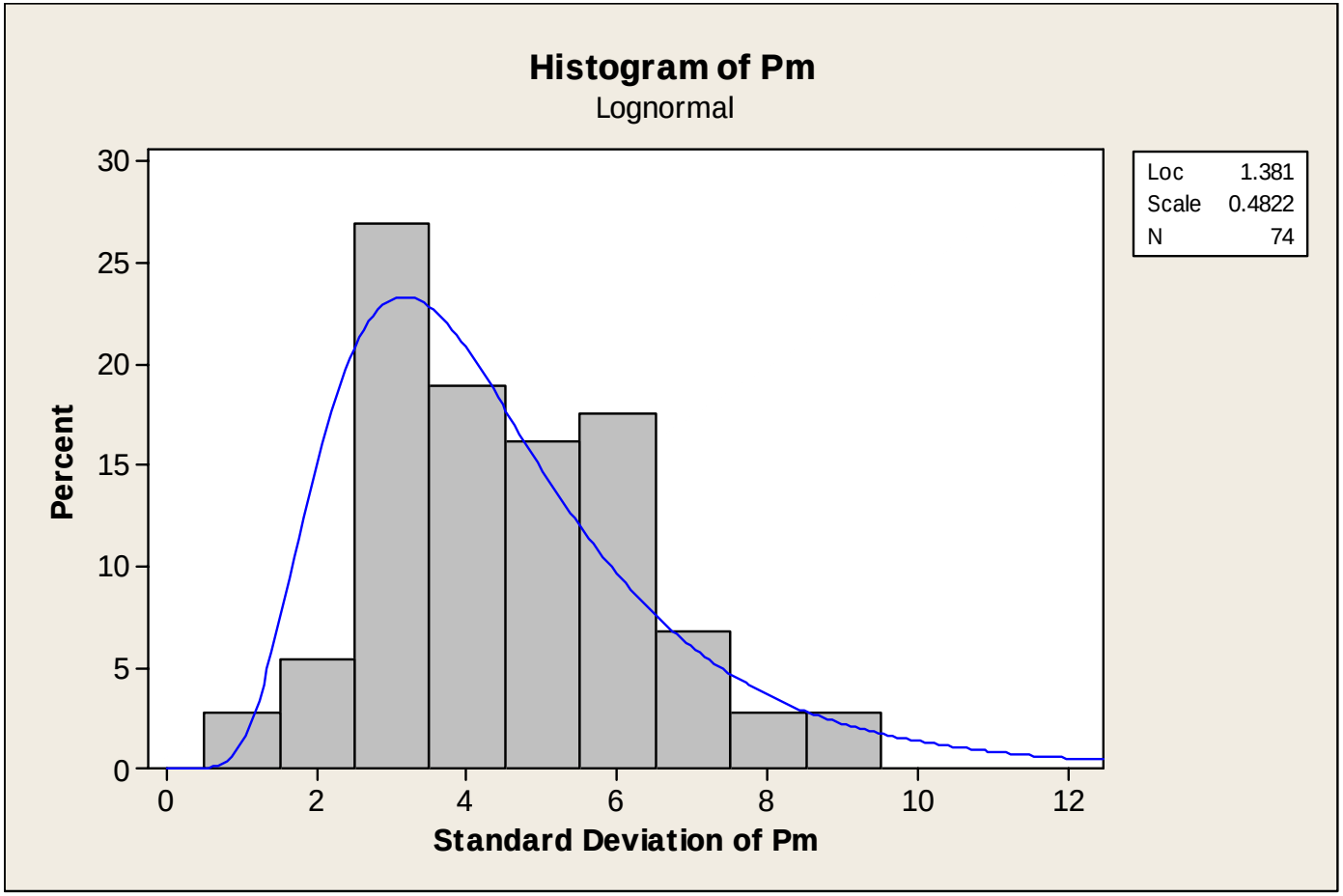
National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Variability of Asphalt Content Non-Fractionated Stockpiles



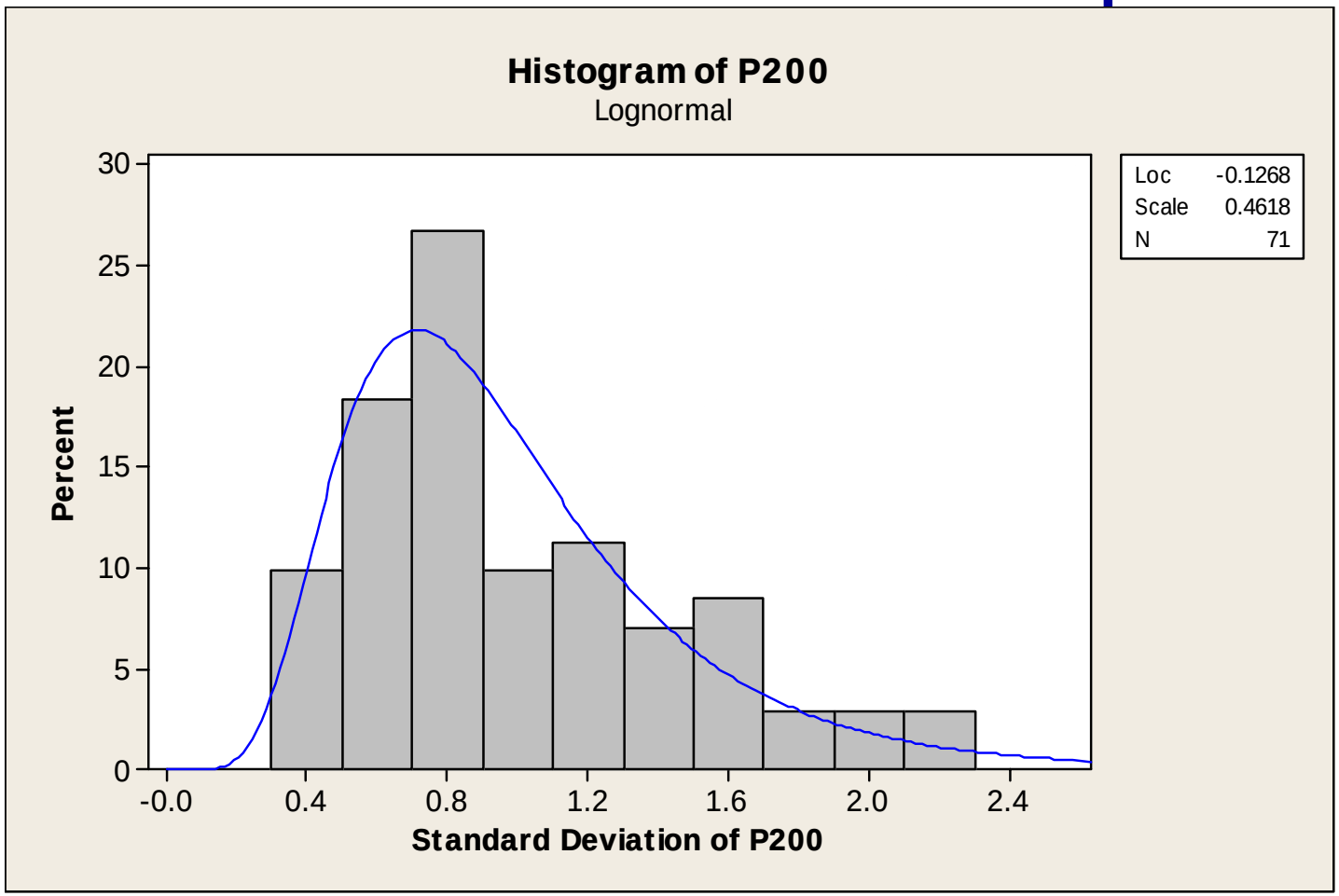
National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Variability of Pm (median sieve) Non-Fractionated Stockpiles



National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Variability of P200 Non-Fractionated Stockpiles



National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Variability of Fractionated RAP

Fractionated Fine RAP			Fractionated Coarse RAP		
Pb	**Pm**	**P200**	**Pb**	**Pm**	**P200**
0.17	2.76	0.64	0.26	1.68	1.18
0.28	3	0.8	0.28	8.2	0.7
0.3	5.3	0.7	0.31	4.52	0.69
0.52	3.7	1.61	0.39	4.02	0.75
0.57	9.6	1.3	0.5	8.3	0.9
0.93	6.3	1.48	0.53	3.5	3.5
1.09	1.6	1.17	0.75	11	1.2

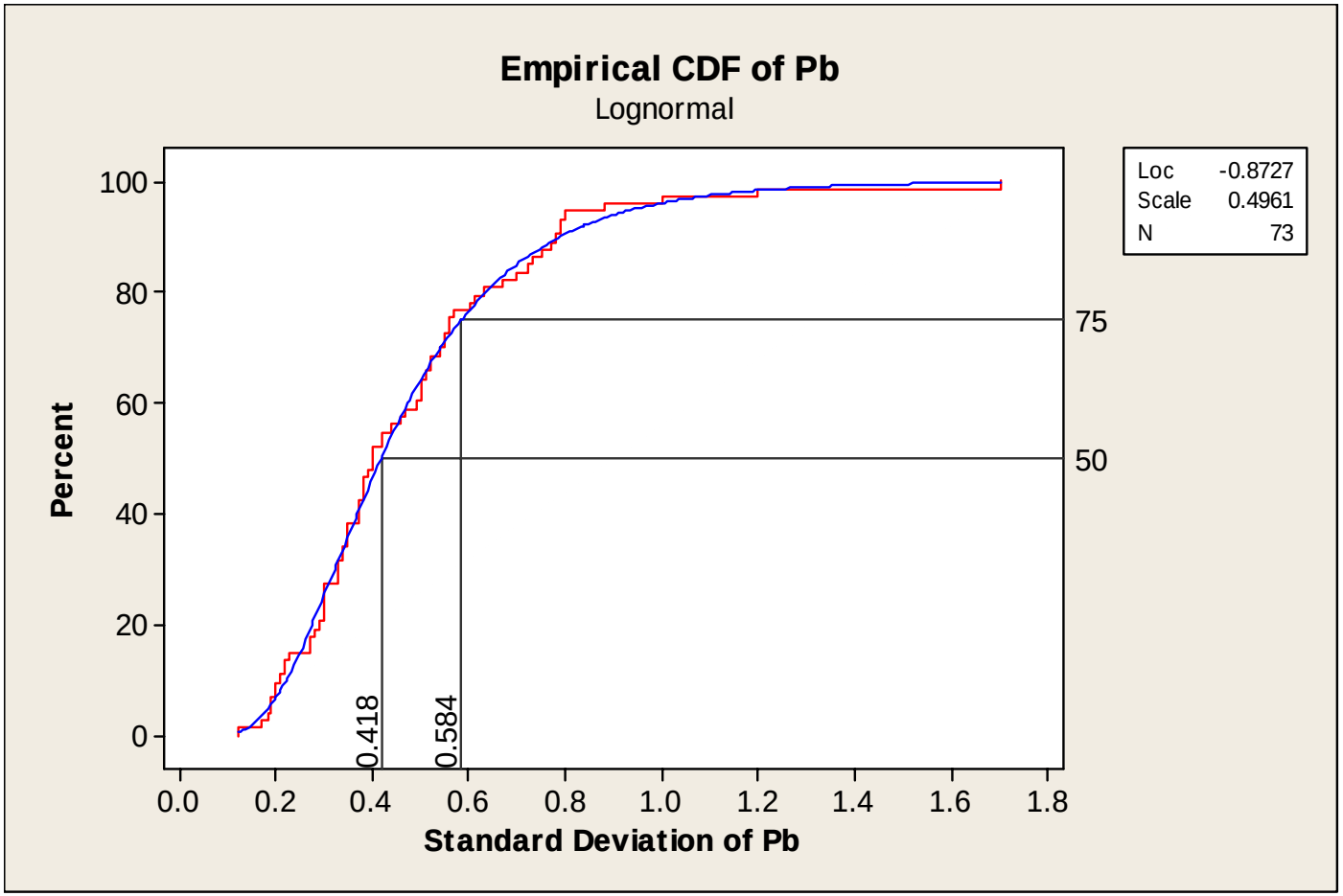
Fractionated vs. non Fractionated

- Data set 1 was non-fractionated standard deviations for Pb, Pm, and P200 (over 70 data points)
- Data set 2A was fractionated RAP coarse, and 2B was fractionated RAP fine (7 data points each)
- Comparison of means and variances of the large and small data sets conducted by Dr. Saeed Maghsoodloo
- Fractionated and non-fractionated data sets were not statistically different except for variance of Pm(coarse). The spread is larger for this fractionated data set.

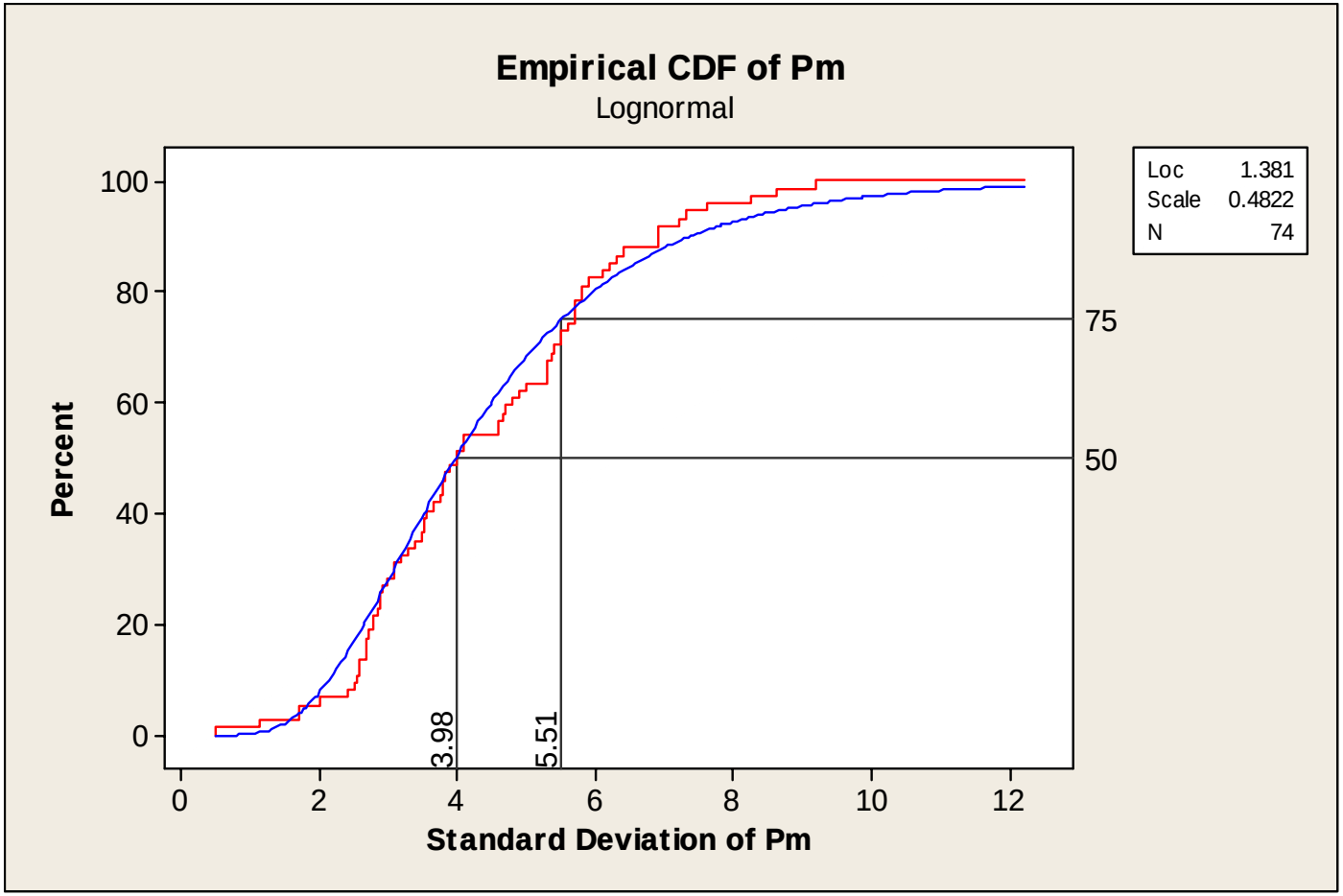
Preliminary Targets for RAP Consistency

RAP property	Max. Standard Deviation (%)
Asphalt Content	**0.5**
% Passing Median Sieve	**5.0**
% Passing 75 micron Sieve	**1.0**

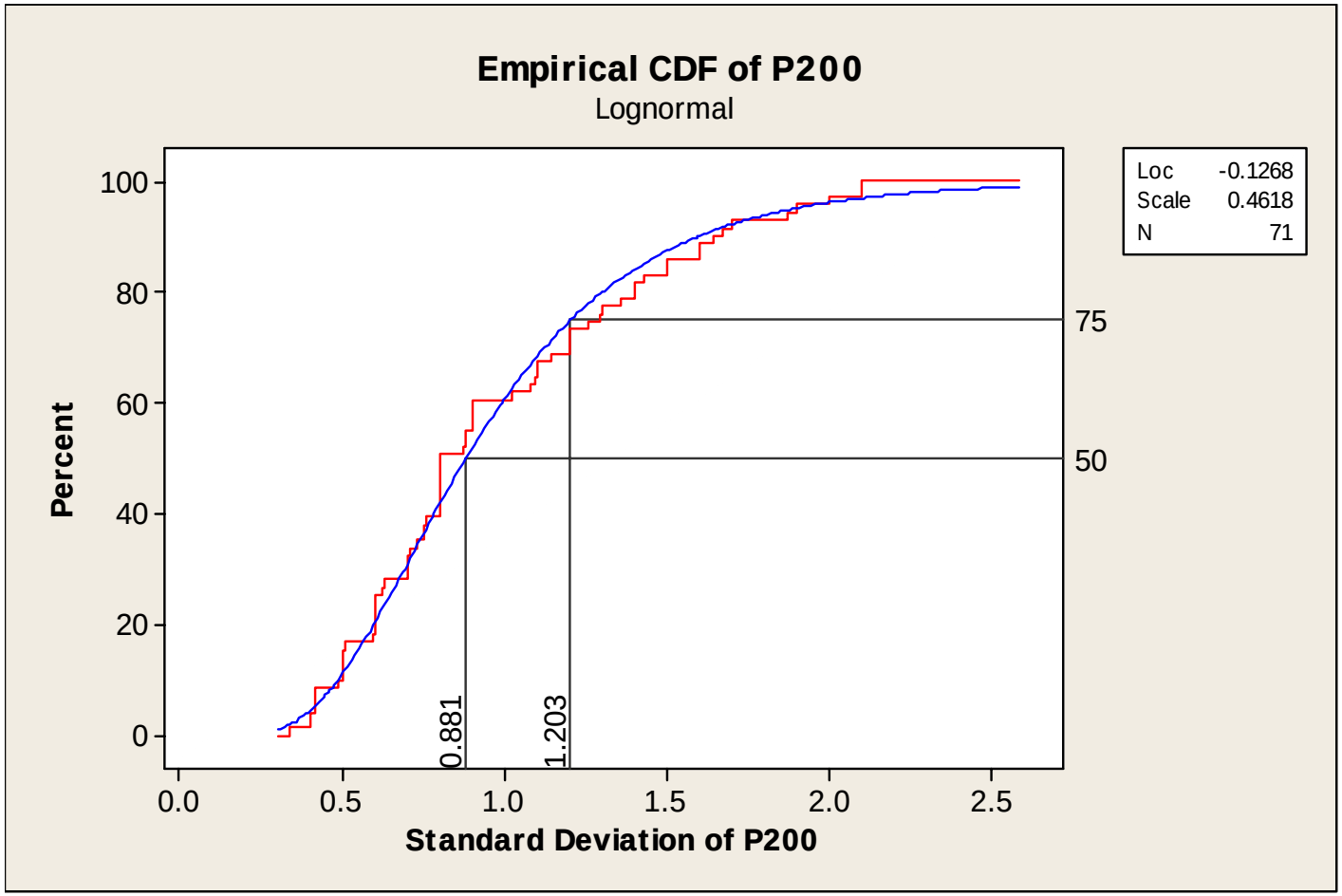
National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY



National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY



National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY



National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Further Work

- Find or collect data for virgin aggregate stockpiles (at the plant site) for further analysis of whether or not RAP is more variable.
- Collect more data for fractionated RAP for analysis of fractionated versus non-fractionated processes
- Compile best practices from contractors who have more consistent stockpiles

Using Component Variabilities in Asphalt Mix Designs

- NCHRP 9-33 introduced the concept of using estimated RAP variability in establishing the maximum content of asphalt mixtures.
- Although this concept appears to be new, it does have merit.
- However, the approach in 9-33 appears to have limitations that can be improved.

The NCAT Approach

- This approach is more general (i.e. it considers the variability of all components, not just RAP, in evaluating a proposed blend of materials).
- This approach is simple to understand and can be set up to work with any mix design spreadsheet.

The NCAT Approach

- The following method of calculating aggregate blends is well established:

$$p = Aa + Bb + Cc + \ldots.$$

- which can be rewritten as:

$$p_{sieve\ S} = \sum_{i=1}^{n} P_i \bar{x}_i$$

$p_{sieve\ S}$ = *percent passing any sieve "S"*
P = *proportion of component "i" in the total blend*
$\bar{x}$ = *average percent passing sieve "S" for component "i"*
n = *total number of aggregate components*

The NCAT Approach

- Similarly, the expected variance of the aggregate blends can be calculated as:

$$\text{var}_{sieve\ S} = \sum_{i=1}^{n} P_i^2 \sigma_i^2$$

$\text{var}_{sieve\ S}$ = *expected variance of percent passing any sieve "S"*

P = *proportion of component "i" in the total blend*

σ^2 = *variance of percent passing sieve "S" for component "i"*

n = *total number of aggregate components*

Assuming that the proportions "P_i" are constants

The NCAT Approach

$$\text{var}_{sieve\ S} = \sum_{i=1}^{n} P_i^2 \sigma_i^2$$

- Actually, the P_i's are not constants, they are also random variables.
- This complicates the matter, but Dr. Maghsoodloo has provided the solution.

The NCAT Approach

Steps

1. Enter the standard deviations of gradations for all aggregate components (including RAP aggregate) into a spreadsheet
2. Calculate the expected variance of the blend (and standard deviation) on each sieve.
3. (Future) Compare the confidence interval of the blend to agency “acceptance” specifications
4. (Future) Make inferences about changes in volumetric properties due to gradation changes and compare to “acceptance” specifications

Further Work

- Complete work on spreadsheet to calculate expected variability of total blend (this approach should be verified with field data).