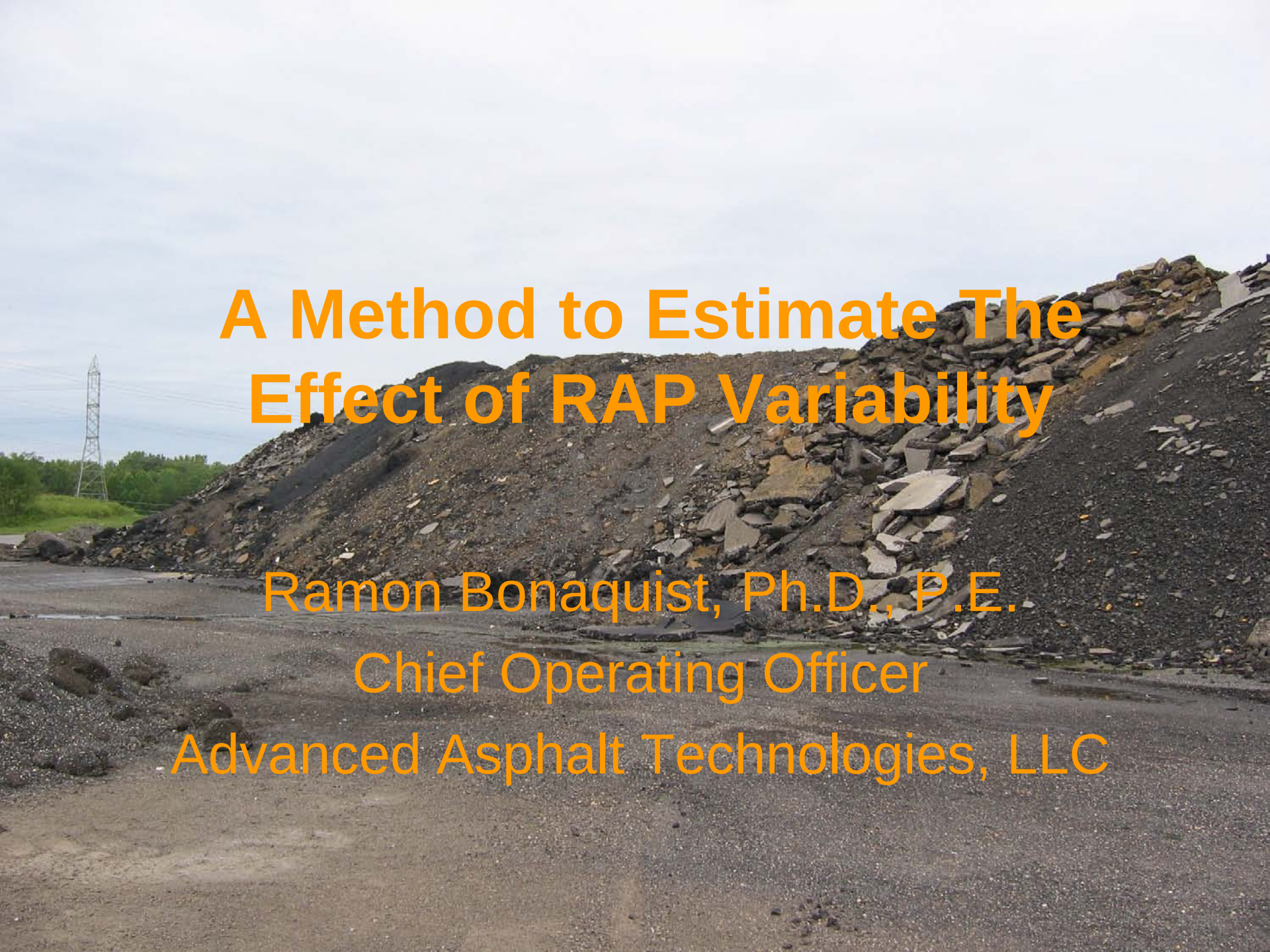

A Method to Estimate The Effect of RAP Variability

Ramon Bonaquist, Ph.D., P.E.
Chief Operating Officer
Advanced Asphalt Technologies, LLC

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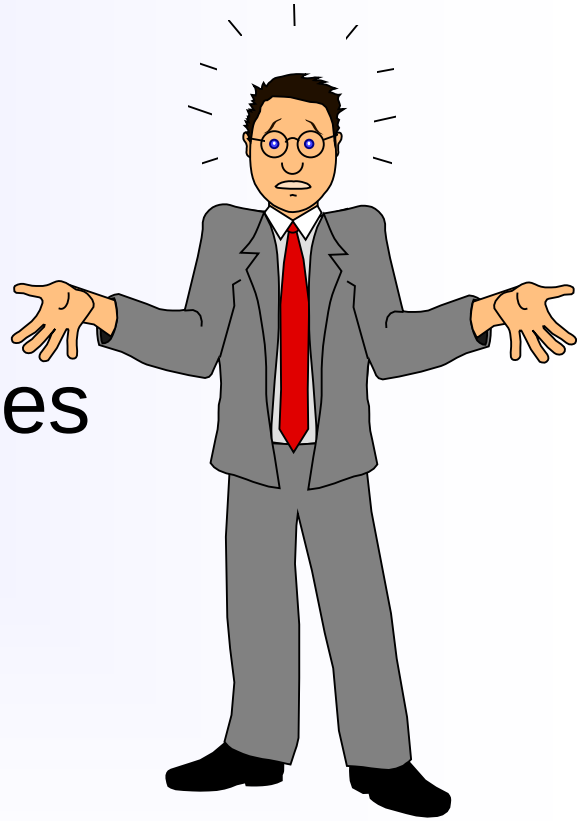
- Principal Investigator: Dr. Donald Christensen, P.E.
- Panel Chair: Frank Fee
- NCHRP Program Officer: Dr. Edward Harrigan

Why Do Agencies Limit RAP Content?

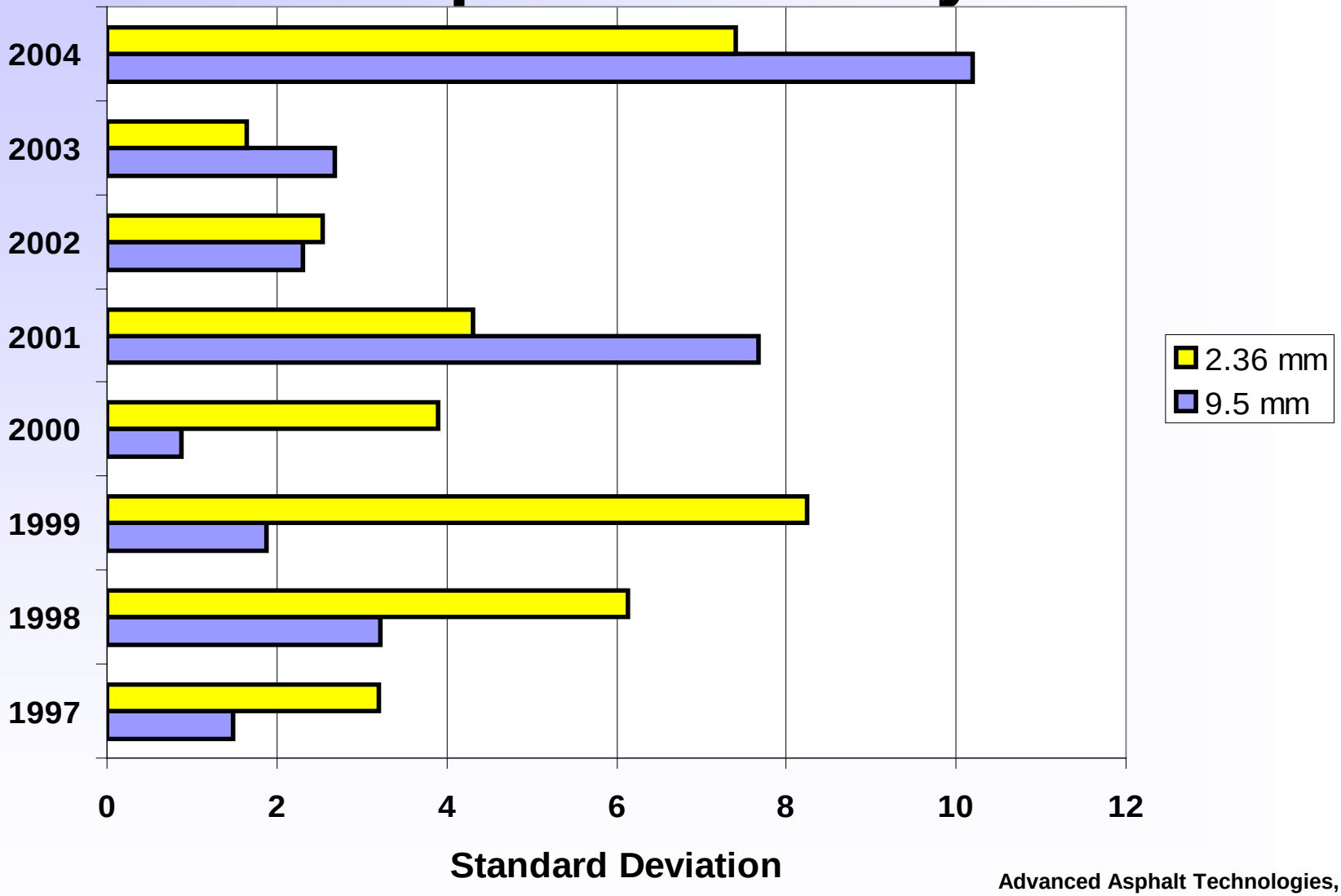
- Binder Grade Changes
- Mixture Homogenity
- Excessive Fines
- Variability of RAP Stockpiles



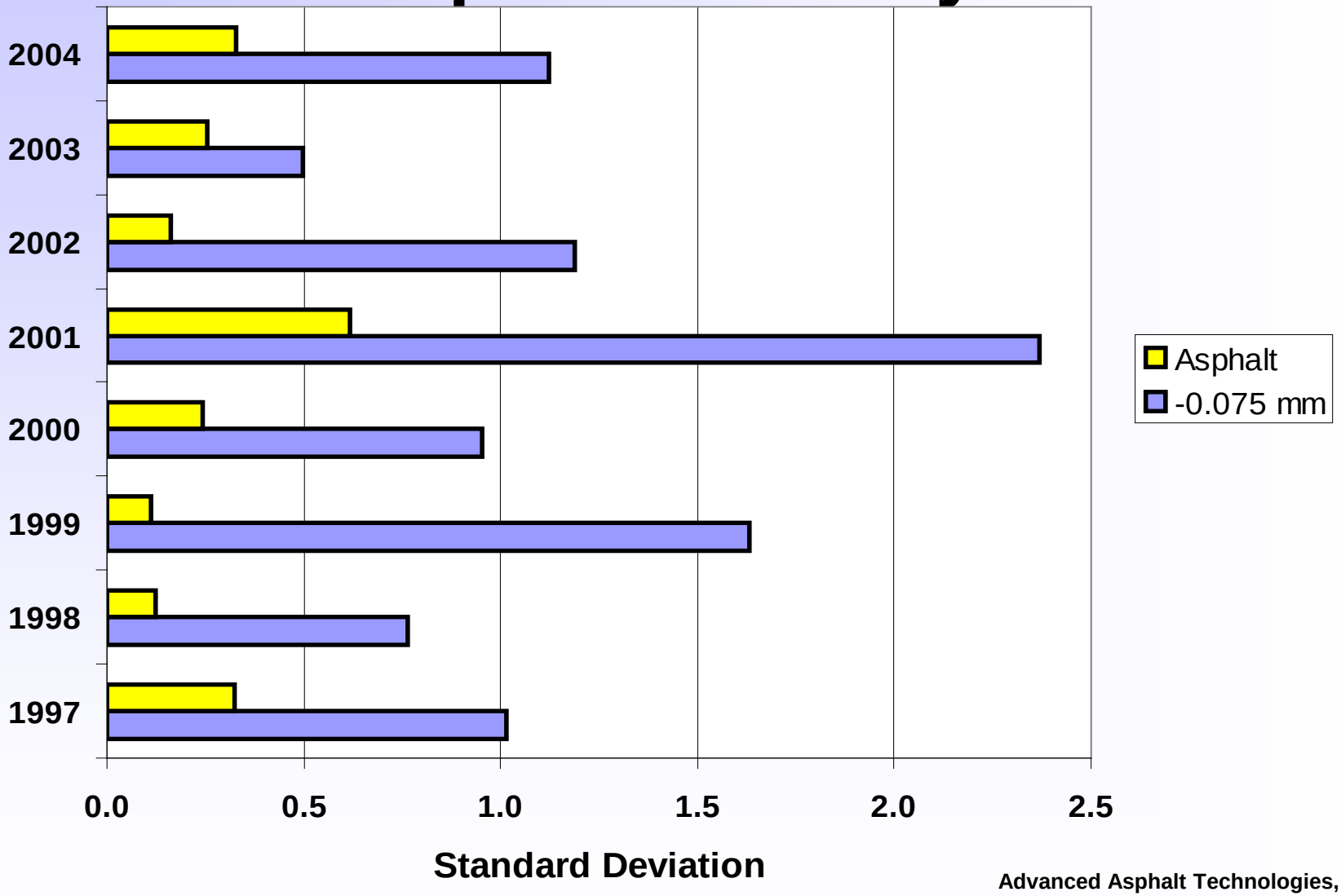
RAP Stockpile Variability

- Variability of Mixture Components Is Major Source of Production Variability
- Must Control Variability to Meet PWL Specifications
- If I Want to Add 45 Percent RAP to a Mix, How Variable Can the RAP Be?
  - Gradation
  - Asphalt Content
- Tool for Mixture Designers

RAP Stockpile Variability

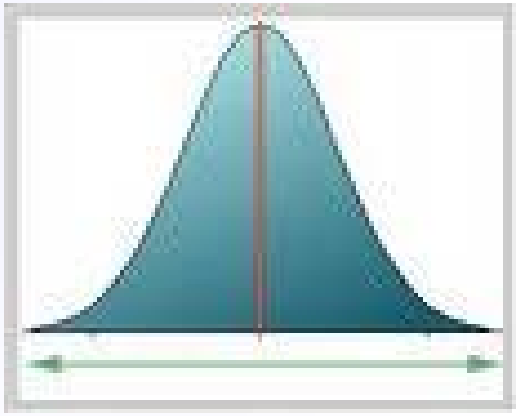


RAP Stockpile Variability



Approaches to Estimate Effect of Stockpile Variability

- Monte Carlo Simulation
  - Simulate Process
- Closed Form Approximate Solution
  - Taylor Series Expansion
- Require Characterization
  - Mean
  - Standard Deviation



Estimate of Mixture Variability

$$\sigma_m = \sqrt{\alpha^2 \sigma_a{}^2 + (1-\alpha)^2 \sigma_b{}^2 + (\overline{X}_a - \overline{X}_b)^2 \sigma_\alpha{}^2}$$

where:

σ_m = standard deviation of the mixture

σ_a = standard deviation of component “a”

σ_b = standard deviation of component “b”

α = proportion of component “a” in the mixture

$\overline{X}_a$ = mean value for component “a”

$\overline{X}_b$ = mean value for component “b”

σ_α = standard deviation of the proportions

Solving for Allowable RAP Variability

$$\sigma_{RAP} = \sqrt{\frac{\sigma_{HMA}^{\,2} - \left(1 - \frac{p_{RAP}}{100}\right)^2 \sigma_{NEW}^{\,2} - \left(\overline{X}_{RAP} - \overline{X}_{NEW}\right)^2 \sigma_{BLEND}^{\,2}}{\left(\frac{p_{RAP}}{100}\right)^2}}$$

where:

σ_{RAP} = allowable standard deviation for the RAP material

p_{RAP} = percentage of RAP in the HMA

σ_{HMA} = allowable standard deviation for the HMA mixture ensuring full compliance with the specifications

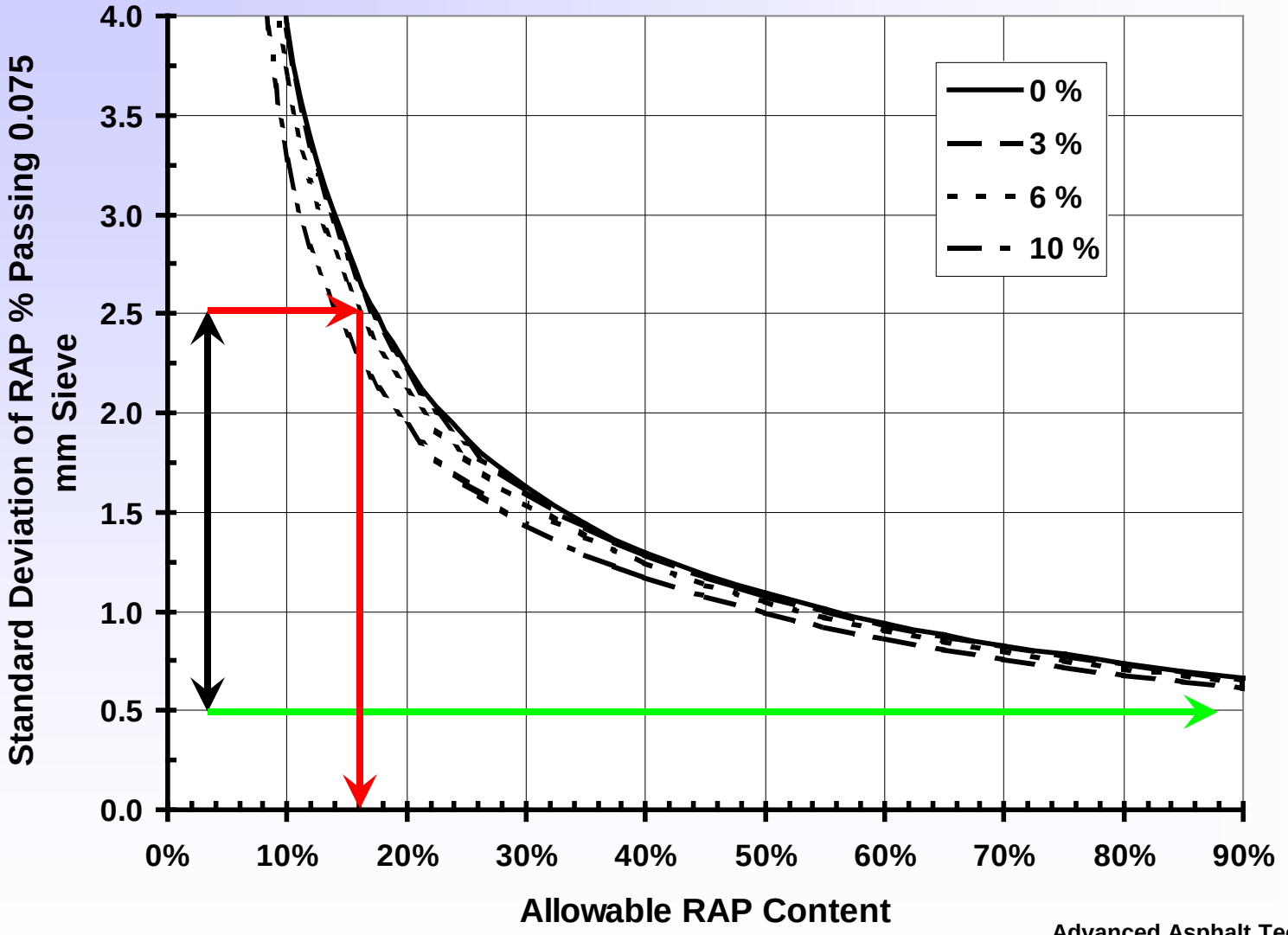
σ_{NEW} = standard deviation for a mixture made with all new materials

σ_{BLEND} = standard deviation for equipment adding the RAP

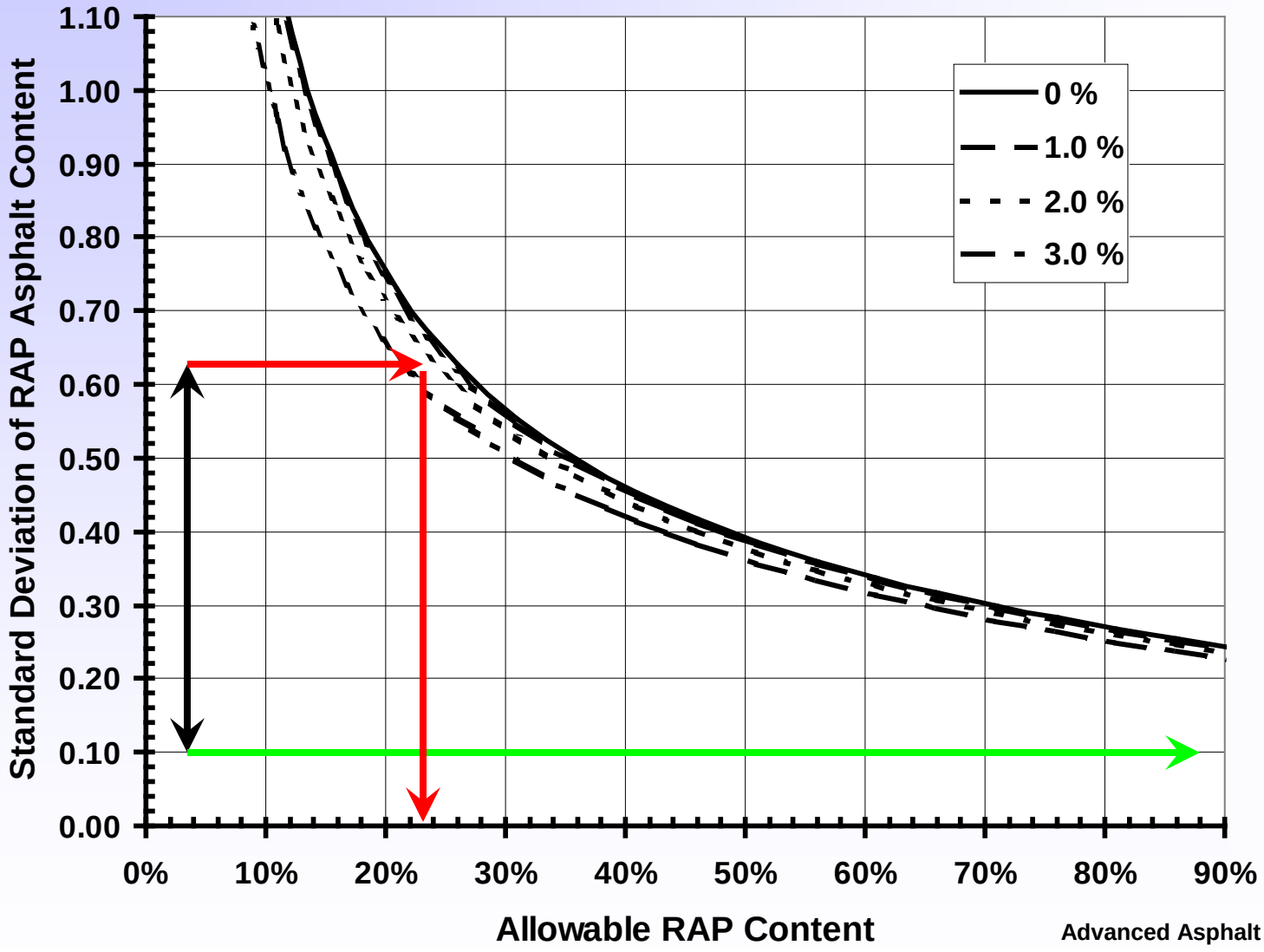
$\overline{X}_{RAP}$ = mean value for the RAP

$\overline{X}_{NEW}$ = mean value for new materials

Example for -0.075 mm Sieve



Example for Asphalt Content



Steps in Analysis

- Sample and Test RAP Stockpiles
  - 10 + Samples Needed for Good Estimate of Standard Deviations
- Determine Standard Deviations of Mixture Made With All New Materials
  - Production Records
- Determine Standard Deviation of Blending Equipment
  - Manufacturer or Testing

Steps in Analysis

- Determine Allowable Standard Deviation to Receive Full Payment
  - Specifications
- Determine Maximum RAP Contents
  - Coarse Aggregate
  - Fine Aggregate
  - Filler
  - Asphalt
- Determine Limiting RAP Content

HMA Tools

- Spreadsheet for mix design
- Aggregate gradation, specification properties, blending
- RAP binder grading/blending, variability analysis
- Volumetric analysis
- Report
- Modulus calculator

Questions?