STATISTICAL SPECIFICATIONS

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Outline

- Introduction
- Definitions
- Statistical Concepts
- Buyers’ and Sellers’ Risks
- Developing Specifications
- Implementation
Introduction

- Types of Specifications
  - Methods and Materials
    - Equipment, Operations, and Materials
  - Performance Related
    - End-Result
      - Desired Outcome
      - Ride
      - Density
      - Asphalt Content
  - Performance Based
    - Test Properties
      - Rutting
      - Cracking
  - Performance
    - Warranty
One option for a statistical specification
- Conformal Limits

The Primary Reasons for PWL Specifications:
- Acceptance on contractor results
- Assess risk for contractor and owner
- Rewards consistency
- Rewards quality

What would lead industry to believe it is not a good deal?
- Misapplications
- Misunderstandings
Definitions

- **Lot**
  - A quantity of product manufactured under a consistent process
    - Tonnage – 4,000 to 10,000
    - Time – day’s production
    - Total – JMF
  - Only changes for change in process, not for minor adjustments to meet limits.
    - JMF, for instance.

- **Sublot**
  - A unit of product that must be sampled to ensure representation of the entire run
    - Tonnage – 500 to 2,000 tons
Lot = 10,000 tons

5 @ 2,000 tons

- Sublot 1
- Sublot 2
- Sublot 3
- Sublot 4
- Sublot 5

Lot = 10,000 tons
Statistical (QA) Specs

Variability

Risks

Buyer

Seller
Sample Mean (Average)

\[
\overline{x} = \frac{\sum_{\text{all } i} x_i}{n}
\]
Sample Standard Deviation

\[ s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}} \]
Measure of Spread (Variability)

\[ S = \sqrt{\frac{\sum_{\text{all } x_i} (x_i - \bar{x})^2}{n-1}} \]
No. of Samples

Standard Deviation

Asphalt Binder Content

4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6
Standard Deviation

X = 5.1

No. of Samples

Asphalt Binder Content

4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6
No. of Samples:

-3s      -2s      -1s                   1s       2s       3s

68% 96% 99.7%

s = standard deviation

68% 96% 99.7%
Standard Deviation

\[ s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} \]

- \( s \) = standard deviation
- \( s^2 \) = variance
# Standard Deviation

<table>
<thead>
<tr>
<th>Sublot</th>
<th>Asphalt Binder Content</th>
<th>Difference from Mean ((x - \bar{x}))</th>
<th>Square of Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.7</td>
<td>-0.4</td>
<td>0.16</td>
</tr>
<tr>
<td>2</td>
<td>5.2</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>5.1</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>5.4</td>
<td>+0.3</td>
<td>0.09</td>
</tr>
<tr>
<td>Sum</td>
<td>20.4</td>
<td></td>
<td>0.26</td>
</tr>
</tbody>
</table>

Mean = \((20.4 ÷ 4) = 5.1\)

Standard Deviation = 0.29

Variance = \((0.29)^2 = 0.08\)
Sources of Variability
Material
Sources of Variability Process
Sources of Variability

Sampling
Sources of Variability Testing
Variability

The overall variability, which is used by the DOT to establish the spec limits, must include:

- Limited material variability.
- Limited process variability.
- Standard sampling variability.
- Standard testing variability.
Measure (control) both the center (*mean*) and spread (*standard deviation*).

Controlling one is not sufficient.

Controlling each separately is also not sufficient!
Center & Spread Relationship

LSL

USL

OK?
Center & Spread Relationship

OK?
Percent Within Limits (PWL)
PWL as a Quality Measure
PWL as a Quality Measure
Example:

Material: Type A, Grade 2
QC/QA data: No. 4 sieve
Target value: 43 from JMF2
Spec limits: Plus or minus 5 percentage points
Test results: 42, 38, 40, 44
Calculating

Average (mean) $\bar{x} = 41$

Standard Deviation

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n - 1}} = 2.58$$
Lower Specification Limit

Target Value

Upper Specification Limit

\( \bar{x} = 41 \)

\( s = 2.58 \)
The diagram illustrates the relationship between the Lower and Upper Specification Limits with the Target Value. The Target Value is represented by \( \bar{x} = 41 \) and the Standard Deviation is given as \( s = 2.58 \).
CHECK THE LOWER LIMIT $Q_L$
\[ Q_L = \frac{41 - 38}{2.58} = 1.16 \]
# PWL ( Q ) Table (FHWA format)

<table>
<thead>
<tr>
<th>PWL</th>
<th>$n = 3$</th>
<th>$n = 4$</th>
<th>$n = 5$</th>
<th>$n = 6$</th>
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<tbody>
<tr>
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<td>1.16</td>
<td>1.50</td>
<td>1.79</td>
<td>2.03</td>
</tr>
<tr>
<td>99</td>
<td>–</td>
<td>1.47</td>
<td>1.67</td>
<td>1.80</td>
</tr>
<tr>
<td>98</td>
<td>1.15</td>
<td>1.44</td>
<td>1.60</td>
<td>1.70</td>
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<tr>
<td>97</td>
<td>–</td>
<td>1.41</td>
<td>1.54</td>
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<tr>
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<td>1.14</td>
<td>1.38</td>
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<td>1.32</td>
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<td>91</td>
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CHECK THE UPPER LIMIT $Q_u$
$\bar{x} = 41$

$s = 2.58$
\[ Q_U = \frac{48-41}{2.58} = 2.71 \]
### PWL (Q) Table (FHWA format)

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<td>1.19</td>
<td>1.20</td>
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PWL = (100 + 89) - 100 = 89%
Calculate Pay Factors

\[ \text{PF} = 0.50 \ (\text{PWL}) + 55 \]
\[ = 0.50 \ (89) + 55 \]
\[ = 44.5 + 55 = 99.5 \]

= 99.5
Determining “Typical” Variability

- State should use a “typical” variability to set spec limits.
- Should be based on variability data from a large number of projects.
- There is no single “correct” way to do this.
“Process Adjustments”

- “I can’t wait to plot a control chart. I need to make an adjustment after each test is in.”
- “With PWL I can’t adjust my process because I get a penalty if I do.”
The natural tendency for someone who does not understand variability is to over adjust a process!

To adjust, or not to adjust, that is the question.
Too much process adjusting leads to increased standard deviations (*no tweaking!*).

- Leading to smaller $Q$ values
- Leading to lower PWL values
- Leading to lower payment!
Buyers’ and Sellers’ Risks

- Buyer’s risk is the probability that an inferior product is accepted.
- Seller’s risk is the probability that an acceptable product is rejected.
- These risks exist regardless of whether the specification is statistically based.
- They can be quantified with statistics so you know where you stand.
- A good specification has a reasonable level of risk for both parties.
What are your risks?

- 2.5 Million people die each year in the U.S.
  - 2.4 Million of disease
  - 0.1 Million of accidents
  - Overall 1 in 134

- Accidents
  - Motor vehicle: 34,000
  - Commercial airline: 0
  - Falling out of bed: 450
  - Lightning strike: 29

CDC, 2010
What are your risks?

- Disease
  - Heart disease: 599,000
  - Mad cow: 0
  - Cancer: 575,000
  - Flu: 50,000
  - Bird flu: 0

- Hedging your bets
  - Don’t drink and drive!
  - Don’t text and drive!
  - Don’t smoke!
  - Eat healthy!

CDC, 2010
Risks

- The future price of asphalt.
- The future price of aggregate.
- The cost of transportation.
- The cost of concrete pavement.
- The cost of labor.
- The price you get for HMA.
- The penalty or bonus.
$PF = 55 + 0.5 \text{PWL}$ and $n = 4$
Desirable Specification Features

• Must be understandable and biddable.
• Product expectations are clearly stated.
• Risks are clearly defined.
• Points of sampling, frequency and tests are unambiguous.
Characteristics are tied to performance.

Historical records are used for quality level and variability.

Precision and bias accounted for in tolerance.

Interdependence of variables accounted for.
Desirable Specification
Features

• All assumptions are clearly stated.

• Do not stifle innovation.

• Provide quick results of QA testing.
What not to do. . .

- Set limits according to testing variability instead of all sources of variability.
- Have small sample sizes with narrow limits.
- Set pay adjustments with steep step functions.
- Apply spec to materials it wasn’t intended for.
What not to do. . .

- Implement PWL without OC curves.
- Have penalties without bonuses.
- Have pay factors based on subplot results.
- Use PWL on noncontinuous projects – driveways, turn lanes, etc.
- Use on small projects.
- Use on unusual projects.
Currently 35 states using “PWL”

Success stories
- Kansas
- Missouri
- Washington

Working with it and refining
- Maryland
- Iowa

Horror stories
- Federal Agency
- State 1
- State 2
PWL Specs are not your enemy …
If you understand them!
They reward contractors with low process variabilities.
They penalize contractors with high process variabilities (so, don’t over adjust!).
Some Observations

- There are no statistical specs with n=1.
- As n increases, risks go down for both contractors and agencies.
- Need realistic targets and limits:
  - Two-sided
  - One-sided
- Requires 5 to 7 years to properly implement.
- Cannot have PF that penalize without PF bonuses.
On Contractor Acceptance...

- Same Tech Cert for Contractor and Agency
- Regular Round-Robin Testing
- Sample Handling
- Agency Laboratory Scheduling
I don’t care what kind of @#%&*! specification it is, if I can make money off of it, it’s a good spec!
Do We Know What Makes a Pavement Perform?

This is not white sand!