# Calibration Interval Adjustment Methods
# Programmatic Cost Effects

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# Learning Objectives

- Understand interval analysis (IA) simulation concepts.
- Judge IA effectiveness by excess test and measurement costs.
- Examine the impacts of realistic calibration scenarios on interval analysis.
- See work that will lead to quantitative method selection guidance in RP-1.

# Why Do Interval Analysis?

- Reduce operating costs
- Reduce consequence costs
- Improve product and process quality
- Justify interval changes quantitatively (Z540.3)
- Leverage your software investment
- Gain competitive advantage

# Why Simulate?

## Complexity

Each method's performance varies with a complex condition set.

- Inventory Parameters
  - Group size
  - Instrument life
  - Reliability behavior
  - Correct interval
  - Resubmission time
  - Interval closure rate
- Programmatic Parameters
  - Reliability target
  - Initial intervals
  - Interval resolution
  - Interval restrictions
  - False accept rate
  - Resubmission windowing

# Terminology

## Acronyms

IA–Interval Analysis
BOPR–Beginning Of Period Reliability, $1 - p_{\mathrm{FA}}$
EOPR–End Of Period Reliability
AOPR–Average Over Period Reliability

Note: All values computed at the instrument level

## Method Designators

Ax–Algorithmic, Sx–Statistical, Ex–Experimental

## Definition

Relative excess cost metric–The excess cost in the test and measurement budget due to imperfect interval analysis, relative to the optimal budget

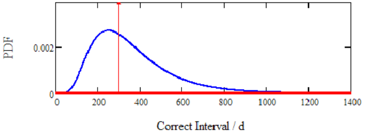
# Review: Implemented Methods

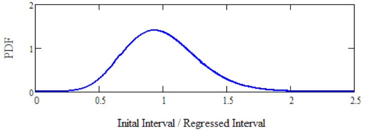
- Currently simulating Methods A1, A2, A3, S1, and E1
- Method Parameters
  - A1 $a \in \{0.01, 0.1\}$
  - A2 $v \in \{1, 2\}$
  - A3 $C \in \{0.5, 0.7, 0.9\}$, interpolation & extrapolation choices
  - S1 "out of the box", always adjust mode only
- Experimental Method E1
  - Greg Cenker constructed it.
  - Fits a two-parameter model to the specified BOPR, observed EOPR, and average resubmission time
    - Linear, exponential, random walk
  - Biases EOPR to speed response with high reliability
  - Configurable action delay
  - Potentially Method A4 in a future RP

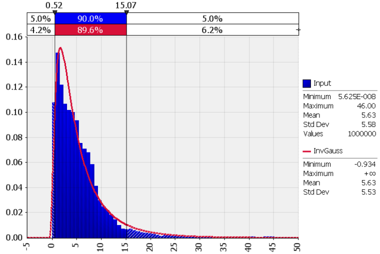
# Recent Work: Test Bed Upgrades

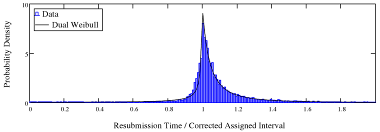
- Distributed equipment group size
- Distributed instrument-application life
- Individual instrument lives
- Distributed resubmission time
- Distributed reliability behavior, BOPR and AOPR selection
- Functional failures and unreturned equipment
- Uniform interval rounding and restrictions
- Analyzed almost 13 years' actual calibration interval data
- The paper details the distributions, simulation steps and reliability models.
- Short-lived conservative interval scenario
- The scenario budget contains $\approxeq 43\ \%$ excess cost.
- Preliminary data–from 1.3 simulators

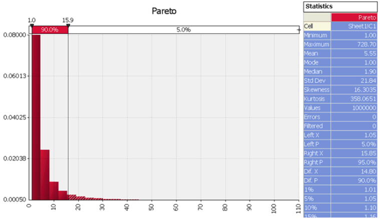
# Example Simulation Input Distributions

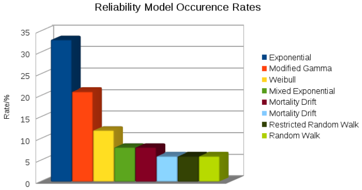


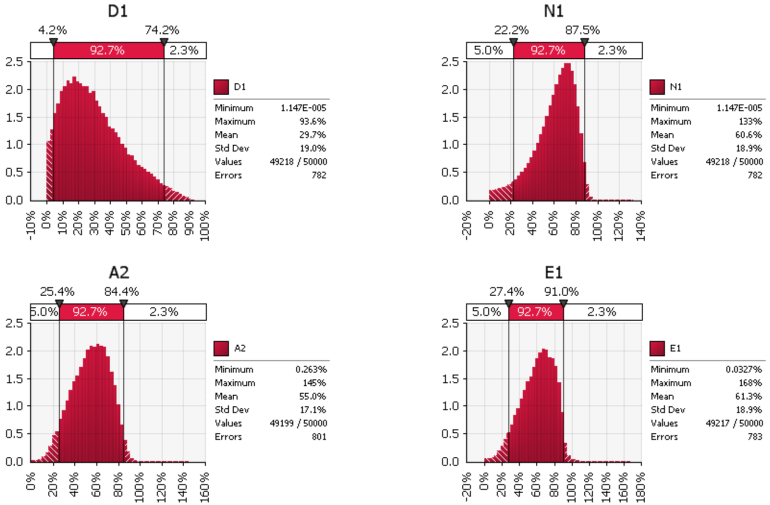



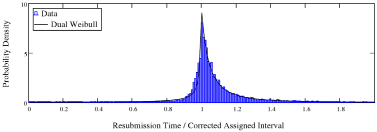
# Example Simulation Output Distributions

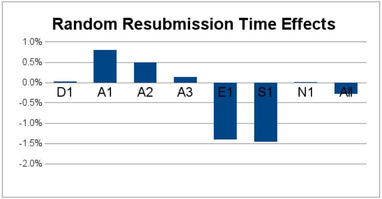


# Programmatic Effects Investigated

- Benchmark: Distributed correct and initial intervals, distributed instrument life, distributed group size
  - Baseline 1: Fixed resubmission time, exponential reliability model, zero inop rate
    - Distributed resubmission time effects
    - Distributed reliability model effects
  - Baseline 2: Distributed resubmission time and model, zero inop rate
    - Default ($\approxeq$ 6.5 %) and 50 % inop rates
  - Baseline 3: Distributed resubmission time and model, default inop rate
    - AOPR and BOPR effects
    - Interval rounding effects
    - Interval restriction effects

# Distributed Resubmission Time



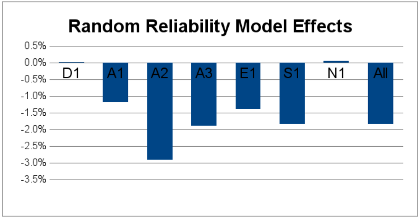

- D1 and N1: only simulation error
- Helps E1 and S1: quicker OOTs?
- Hurts A1 and A2.
- A3 loses less when its aggression increases with reliability target.

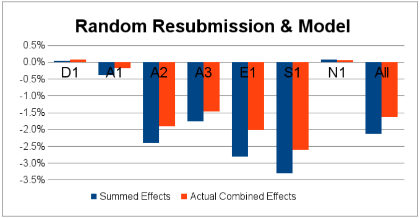
- No large overall effect on IA
- Different management strategies for different methods

# Distributed Reliability Behavior

| Reliability Model | Rate |
|---|---|
| Exponential | 33 % |
| Modified Gamma | 21 % |
| Weibull | 12 % |
| Mixed Exponential | 8 % |
| Mortality Drift | 8 % |
| Warranty | 6 % |
| Restricted Random Walk | 6 % |
| Random Walk | 6 % |

- Dr. Castrup's experience
- Mortality model questionable
- Algorithmic methods more resilient (with more data)

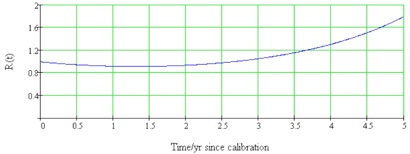


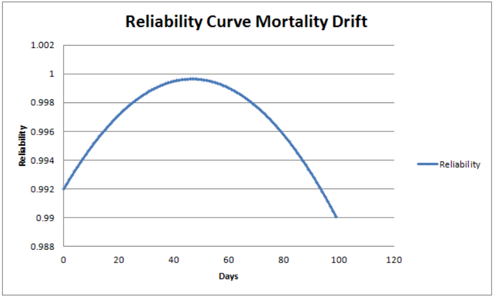

- Non-linear total response

# Mortality Drift Model

$$R_{\text{mort}}(t, \Theta) = \Theta_0 e^{-\left(\Theta_1 t + \Theta_2 t^2\right)}$$

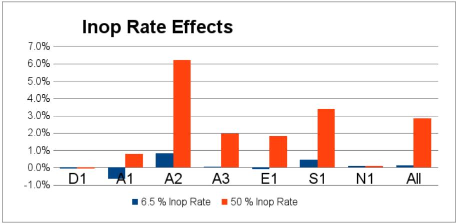



Mortality Drift Reliability Model



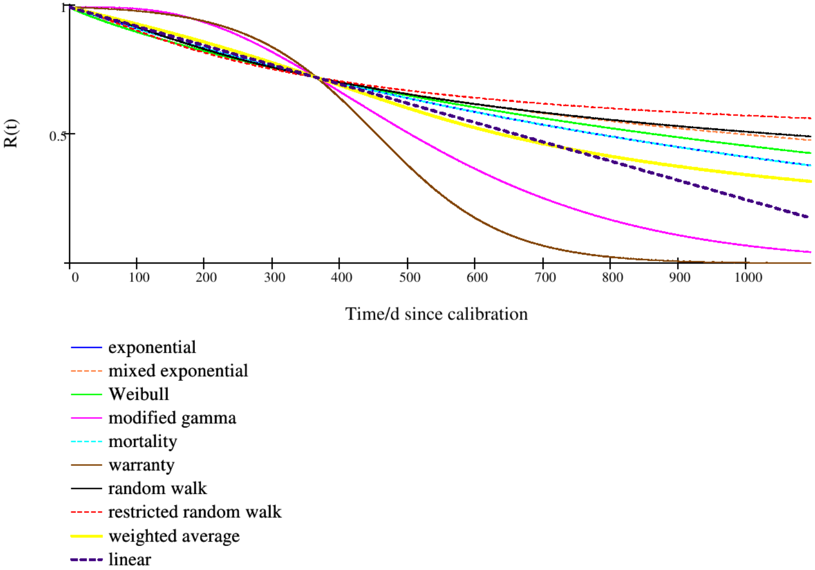
# Inop Rate: Wait! No Calibration Data

- $\approxeq 6.5\ \%$ of calibrations yielded no accuracy-related data
- Inoperative or unreturned equipment: unknown state
- Calibration intervals only control measurement reliability

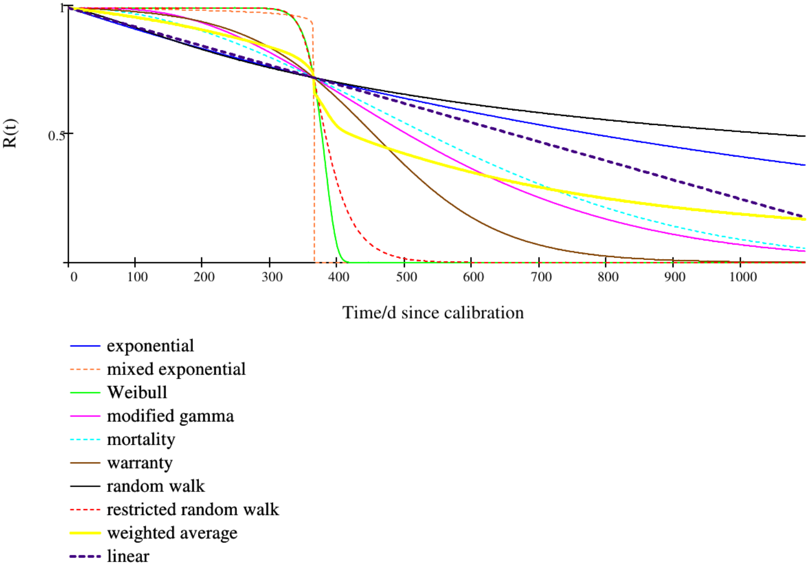



- Hurts both algorithmic and statistical methods
- Small overall effect
- Reduces A1's activity

# Mid-Range AOPR Behavior



# Extremely High AOPR



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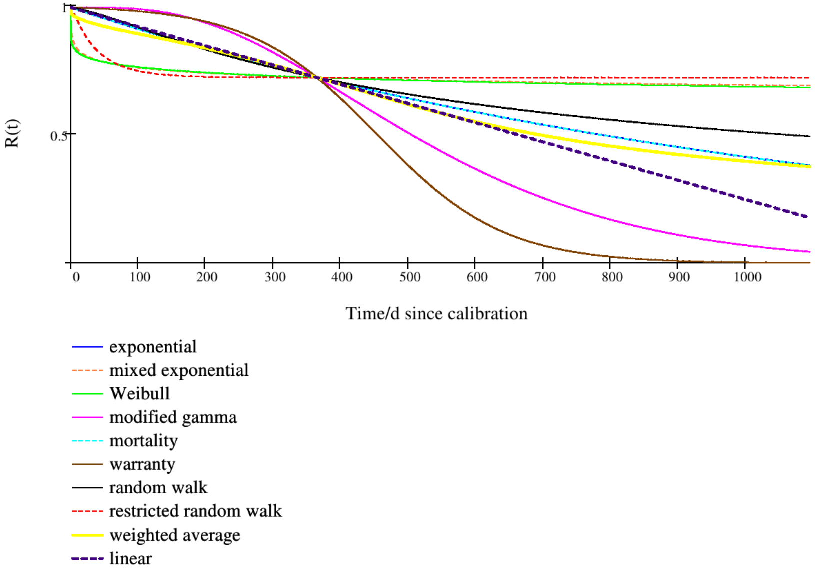
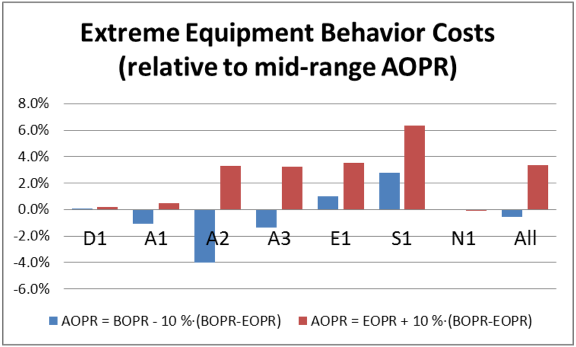
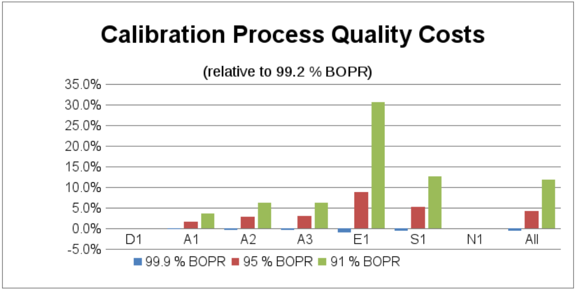


# Extreme Equipment Behavior



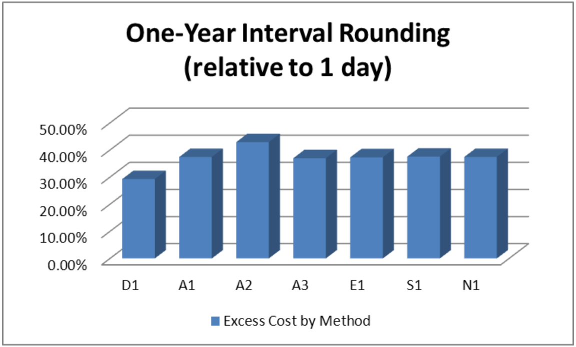

- Extreme behavior counters modeling advantages (S1, E1).
- Low AOPR reduces interval error detection sensitivity.
- A likely opportunity for Method S2

# BOPR (False Accept) Effects



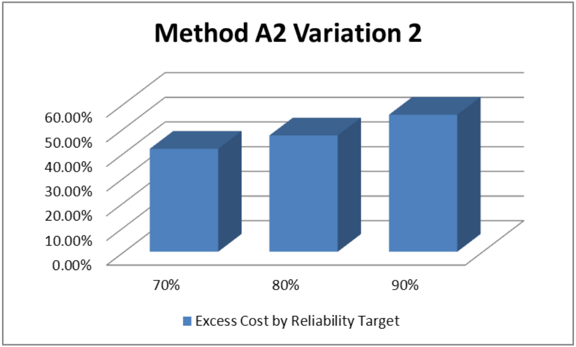

- High sensitivity to BOPR, especially at high reliability targets
- Violates S1's model.
- E1 should compensate but doesn't.
- Even effects algorithmic methods.

# Large Interval Units



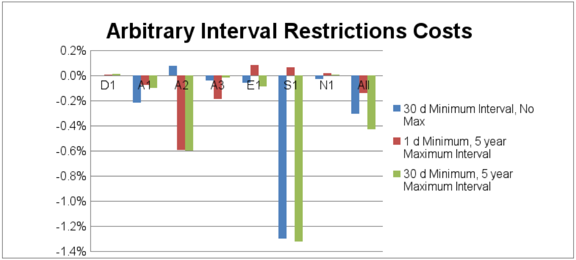

- One-year interval increments negates all methods.
- Method A2 does worse than nothing.
- Even perfect analysis fares poorly.
- RP-1 does not recommend interval rounding.

# Method A2, Variation 2 Detail




- Higher targets allow larger interval adjustments.
- A2 V2 allows interval increases as large as decreases.
- May jump to and converge on the wrong interval increment.
- Other methods do not overcome the large increments.

# Interval Restrictions




- Correct intervals ranged from $\approx 40$ d to $\approx 3.3$ yr.
- The maximum interval restrained Method A2 excesses.
- The minimum interval restrained Method S1 excesses.
- RP-1 does not recommend arbitrary restrictions.

# Summary

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- Low calibration quality strongly impacts costs, especially for statistical methods. ✓
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Method S2 has an opportunity to regain some ground.

# Summary

- Statistical methods handle random resubmission time. ✓
- No methods fail under non-exponential behavior. x
- Inoperative equipment has no large impact. x
- Extreme equipment behavior counters simple modeling. ✓
- Low calibration quality strongly impacts costs, especially for statistical methods. ✓
- One-year interval increments negate interval analysis. ?
- Interval restrictions may help Methods A2 and S1. ?
- Method E1's linear model performs as well as the exponential and random walk models overall. ?

Some results also apply to large data sets. Unexpected gains may evaporate.

# Research on the Horizon

- Work remaining
  - Distribute AOPR and BOPR
  - Simulate remaining methods
    - Particularly Method S2
    - S1 (Dwyer, Huang, Jackson) and A3 (Castrup) variants
    - S3? Variables data Methods?
  - Optimize each method over the reliability target space
  - Map optimal methods to equipment management scenarios
- Caveats
  - Probably more subtleties in the data
  - Metric limitations
  - Missing niceties: resubmission windows, equipment aging, etc.

# Acknowledgments


## Acknowledgments

- B&W Pantex Metrology
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Thank You for your time! Questions?