Mixed Data Type Exponential Smoothing For Reliability Prediction

Lt Jeremy L. Thompson

49 TES

30 January 2012

This Briefing is:

UNCLASSIFIED

Overview

- Background
- Current Method
- Proposed Method
- Models
- Simulation
- Analysis
- Summary

Background

- **Currently Advanced Weapon Systems Analyst**
  - **ALCM testing and analysis**
  - **Aircraft nuclear reliability/accuracy for USSTRATCOM**

Project Background

- ALCM analysis presents challenges
  - Irregular testing schedule
  - Different types of testing
  - Annual projection required

- Exponential Smoothing selected
  - Accommodates irregular schedule with annual average
  - Allows projection

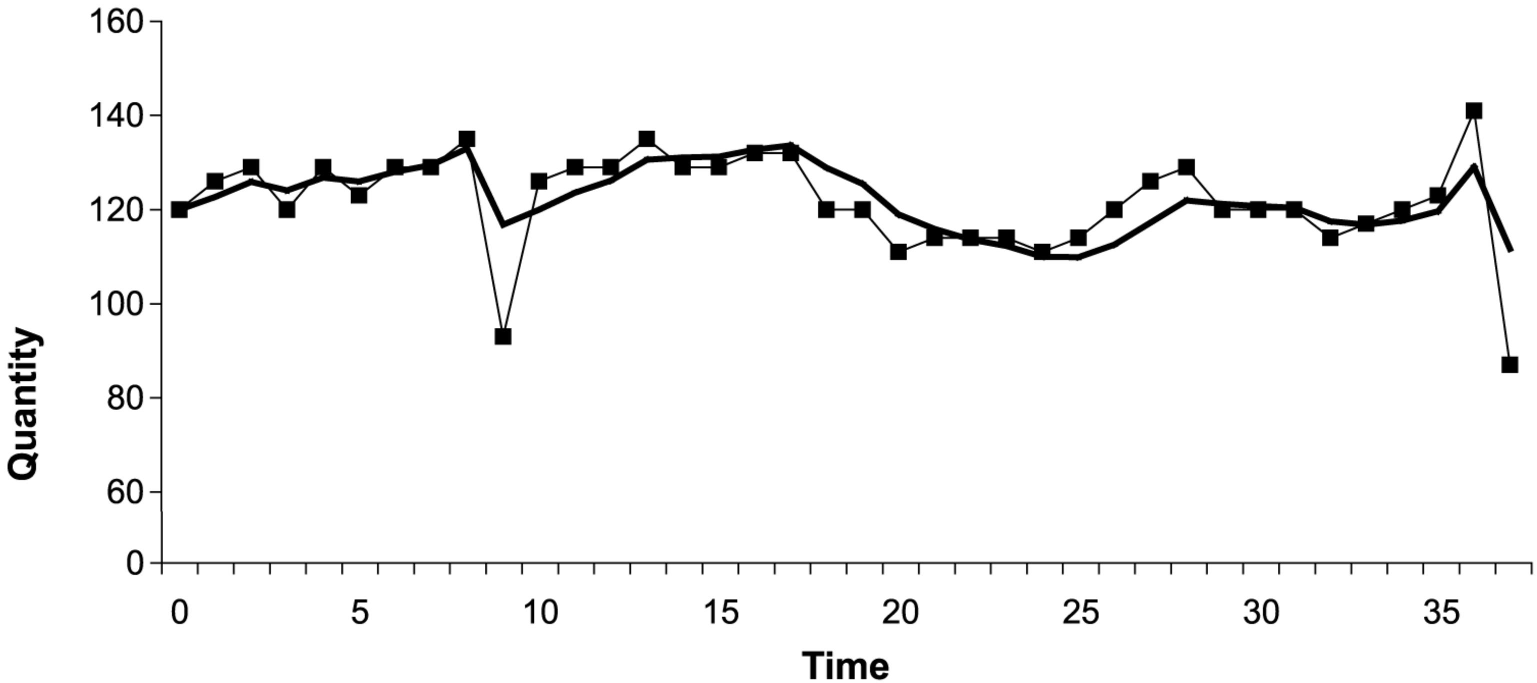
Time Series

- Data collected at uniform intervals, such as test successes over tests attempted, forms a time series

- Time series analysis consists of methods for analyzing time series data to extract meaningful statistics and other characteristics of the data

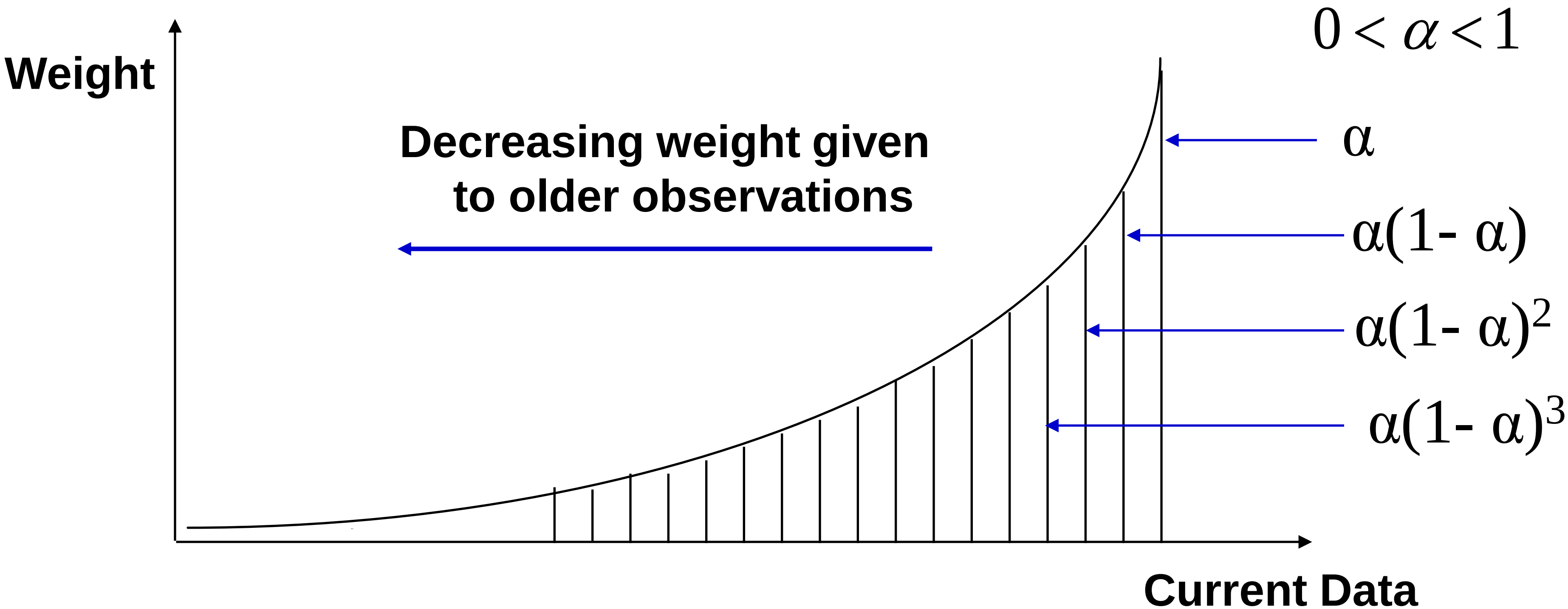
Simple Exponential Smoothing

- Simple Exponential Smoothing works well with data that is stationary, or "moving sideways"



Simple Exponential Smoothing

- New forecast is the weighted sum of old forecast and new test results
- Weighting factor (smoothing constant), α is chosen to minimize error



Assumptions of Models

- Assumptions of Time Series Models
  - There is information about the past
  - This information can be quantified in the form of data
  - The pattern of the past will continue into the future

- Assumptions of Simple Exponential Smoothing
  - Error is randomly distributed
  - Data is stationary, does not exhibit a long term trend

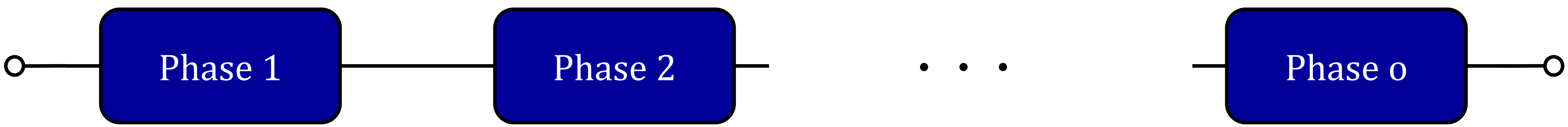
Advantages/Drawbacks

- **Advantages:**
  - **Good accuracy for short-term**
  - **Simple model**
  - **Not highly sensitive to small sample size**
  - **Accounts for changes/corrections to the system**
    - **Recent data given more weight than old data**

- **Drawbacks**
  - **Assumes performance will be like recent history**
  - **Not sensitive to dramatic positive/negative changes in data**
  - **Inaccurate recent year data can cause significant prediction error**

Overall Model

Phase 1 Phase 2 Phase o



- System considered as a whole
- Multiple phases of operation

Current Method

- Estimates annual reliability with test success rate
- Form time series from annual reliability estimates
- Simple exponential smoothing to project future reliability

$$P_t = \alpha \overline{R}_{t-1} + (1-\alpha) P_{t-1}$$

$$t > 1$$

Exponential Smoothing Equation

$$\overline{R}_{t-1} = \frac{S_{t-1}}{S_{t-1} + F_{t-1}}$$

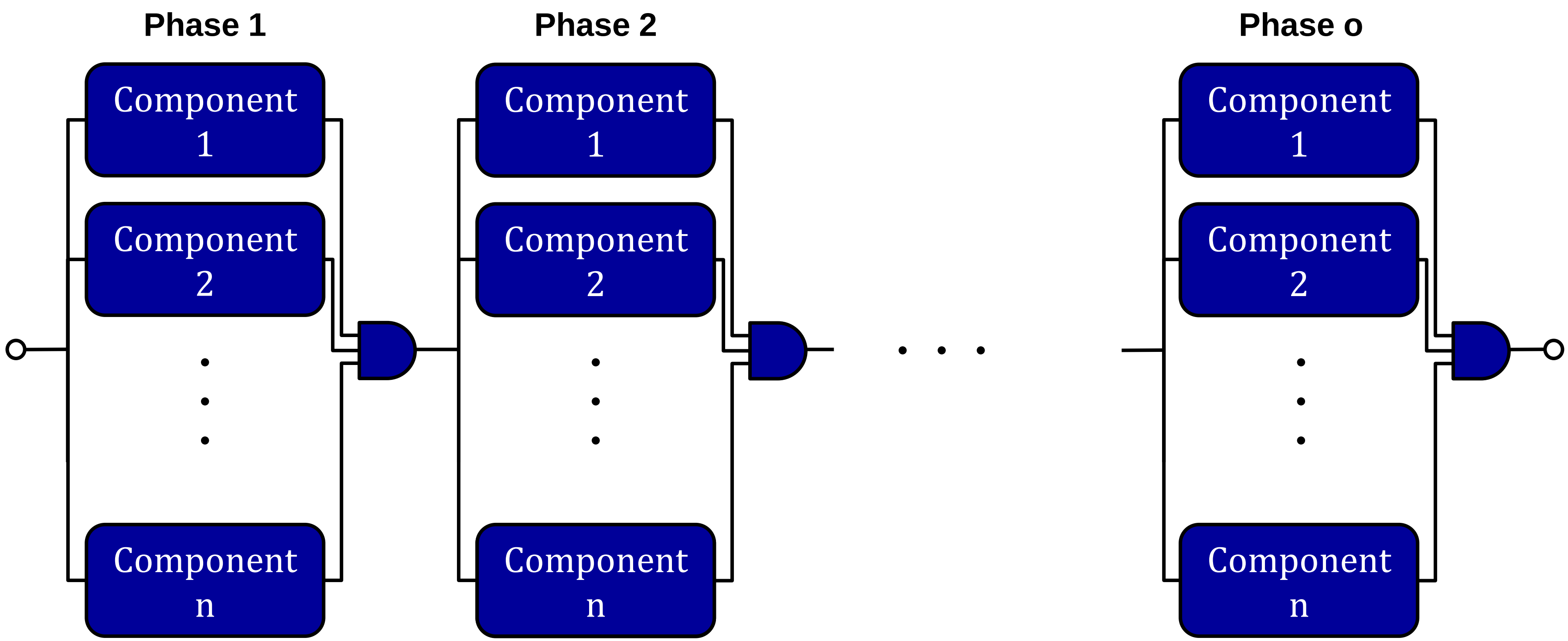
Annual Reliability Estimate Equation

P_t - Projection at time t
R_t - Reliability at time t
S_t - Flight Test successes at time t
F_t - Flight test failures at time t
t - Time index
α - Alpha value

Mixed Data Types

- Live fire testing is cost prohibitive
- Other testing stresses different system components more or less than live fire testing
- Need to model reliability at component level to incorporate different types of testing

Overall Model



- Multiple serial components
- Multiple phases of operation

Proposed Method

- Estimates annual reliability with product of component test success rates
- Incorporates mixed types of data

$$P_t = \alpha \overline{R}_{t-1} + (1-\alpha) P_{t-1}$$

$$t > 1$$

Exponential Smoothing Equation

$$\overline{R}_{t-1} = \prod_{i=1}^{n} \prod_{j=1}^{o} R_{i,j}$$

Annual Reliability Estimate Equation

P_t - Projection at time t	α - Alpha value
R_t - Reliability at time t	i - Component
t - Time index	j - Phase

Test Weighting

- Relative weights for different types of testing, phases of operation, and components

Test Phase	1					2					···	o				
Component	Test Type					Test Type					···	Test Type				
	FT	1	2	···	m	FT	1	2	···	m	···	FT	1	2	···	m
1	1.0	1.0	1.3	···	0.9	1.0	1.0	0.8	···	0.0	···	1.0	1.0	0.8	···	0.0
2	1.0	0.7	1.0	···	1.0	1.0	0.9	1.5	···	0.5	···	1.0	0.9	1.5	···	0.5
3	0.0	0.0	0.0	···	0.0	1.0	0.2	0.7	···	1.0	···	1.0	0.2	0.7	···	1.0
···	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···
n	1.0	0.9	0.8	···	1.0	1.0	0.9	1.0	···	1.5	···	1.0	0.9	1.0	···	1.5

Model 1

$$R_{i,j} = \frac{S_{i,j,FT}}{S_{i,j,FT} + F_{i,j,FT}}$$

- **Flight Testing only**
- **Control model**

R_t - Reliability at time t
$S_{i,j,FT}$ - Flight Test successes for component i, phase j

$F_{i,j,FT}$ - Flight test failures for component i, phase j
t - Time index

Model 2

$$R_{i,j} = \frac{S_{i,j,FT} + S_{i,j,T1} + \cdots + S_{i,j,Tm}}{S_{i,j,FT} + F_{i,j,FT} + S_{i,j,T1} + F_{i,j,T1} + \cdots + S_{i,j,Tm} + F_{i,j,Tm}}$$

- **Simple average**
- **Control model**

R_t - Reliability at time t
$S_{i,j,FT}$ - Flight Test successes for component i, phase j
$S_{i,j,Tm}$ - Test type m successes for component i, phase j
$F_{i,j,FT}$ - Flight test failures for component i, phase j
$F_{i,j,Tm}$ - Test type m failures for component i, phase j
t - Time index

Model 3

$$R_{i,j} = \frac{S_{i,j,FT} + S_{i,j,T1} \cdot W_{i,j,T1} + \cdots + S_{i,j,Tm} \cdot W_{i,j,Tm}}{S_{i,j,FT} + F_{i,j,FT} + S_{i,j,T1} \cdot W_{i,j,T1} + F_{i,j,T1} + \cdots + S_{i,j,Tm} \cdot W_{i,j,Tm} + F_{i,j,Tm}}$$

- **Weighted Successes Model**

R_t - Reliability at time t
$S_{i,j,FT}$ - Flight Test successes for component i, phase j
$S_{i,j,Tm}$ - Test type m successes for component i, phase j
$F_{i,j,FT}$ - Flight test failures for component i, phase j
$F_{i,j,Tm}$ - Test type m failures for component i, phase j
$W_{i,j,Tm}$ - Weight for test type m, component i, phase j
t - Time index

Model 4

$$R_{i,j} = \frac{S_{i,j,FT} + S_{i,j,T1} + \cdots + S_{i,j,Tm}}{S_{i,j,FT} + F_{i,j,FT} + S_{i,j,T1} + F_{i,j,T1} / W_{i,j,T1} + \cdots + S_{i,j,Tm} + F_{i,j,Tm} / W_{i,j,Tm}}$$

- **Weighted Failures Model**

R_t - Reliability at time t
$S_{i,j,FT}$ - Flight Test successes for component i, phase j
$S_{i,j,Tm}$ - Test type m successes for component i, phase j
$F_{i,j,FT}$ - Flight test failures for component i, phase j
$F_{i,j,Tm}$ - Test type m failures for component i, phase j
$W_{i,j,Tm}$ - Weight for test type m, component i, phase j
t - Time index

Simulation

- Coded in Fortran 90
  - Input
  - Set of component reliabilities for each phase
- Number of each type of test
- Simulates 100,000 test years
- Compares estimated system reliability to input system reliability for each model
- Output
  - Mean error for estimate from input reliability for each model
  - Standard deviation of errors for each model

Simulation Parameters

- Several adjustable parameters for the simulation
  - Number of types of tests
  - Number of tests of a type
  - Number of components
  - Number of phases
  - Test weights
  - True component reliabilities
  - True system reliability

2 - 5

1 - 10

30 - 45

1 - 3

Varies

Varies

~0.5 - ~0.9

Simulation

```
!-----------------------------------------------------------------------------------------------------
! Mixed Data Type Exponential Smoothing
! For Reliability Prediction - Model Selection

! Author: Jeremy L. Thompson

! 04 November 2011

! This algorithm compares the average performance of 4 potential models for integrating mixed data types into exponential smoothing
! for reliability prediction.

!-----------------------------------------------------------------------------------------------------
! Models:

! Model 1: [S_T1] /
!          [S_T1 + F_T1]

! Model 2: [S_T1 + S_T1 + ... + S_Tm] /
!          [S_T1 + F_T + S_T1 + F_T1 + ... + S_Tm + F_Tm]

! Model 3: [S_T1 + S_T2 * W_T2 + ... + S_Tm * W_Tm] /
!          [S_T1 + F_T1 + S_T2 * W_T2 + F_T2 + ... + S_Tm * W_Tm + F_Tm]

! Model 4: [S_T1 + S_T2 + ... + S_Tm] /
!          [S_T1 + F_T1 + S_T2 + F_T2 / W_T2 + ... + S_Tm + F_Tm / W_Tm]

! Notes:
!       Models 1 and 2 are control models
!       Models 3 and 4 are candidate models
!       If a weight factor is 0, then the success or failure of that test is not included
!-----------------------------------------------------------------------------------------------------

program modelselect

!-----------------------------------------------------------------------------------------------------
! Part 0: Setup
!-----------------------------------------------------------------------------------------------------

     !------------------------------------------------------------------------------------------------
     ! 0.1 Define variables
     !------------------------------------------------------------------------------------------------
     implicit none
     real (kind = 8) :: random, relt, wgtf, wgts
```

Tested Parameter Combinations

Extreme combinations	Min	Max
Number of types of tests	2	5
Number of tests of a type	1	10
Number of components	30	45
Number of phases	1	3
Test weights	Varies	
True component reliabilities	Varies	
True system reliability	~0.5	~0.9

Tested Parameter Combinations

- **Center combinations**

Parameter	Min	Max
Number of types of tests	3	4
Number of tests of a type	5	5
Number of components	37	38
Number of phases	2	2
Test weights	Varies	
True component reliabilities	Varies	
True system reliability	~0.7	~0.7

Analysis Parameters

- Parameters were consolidated for analysis

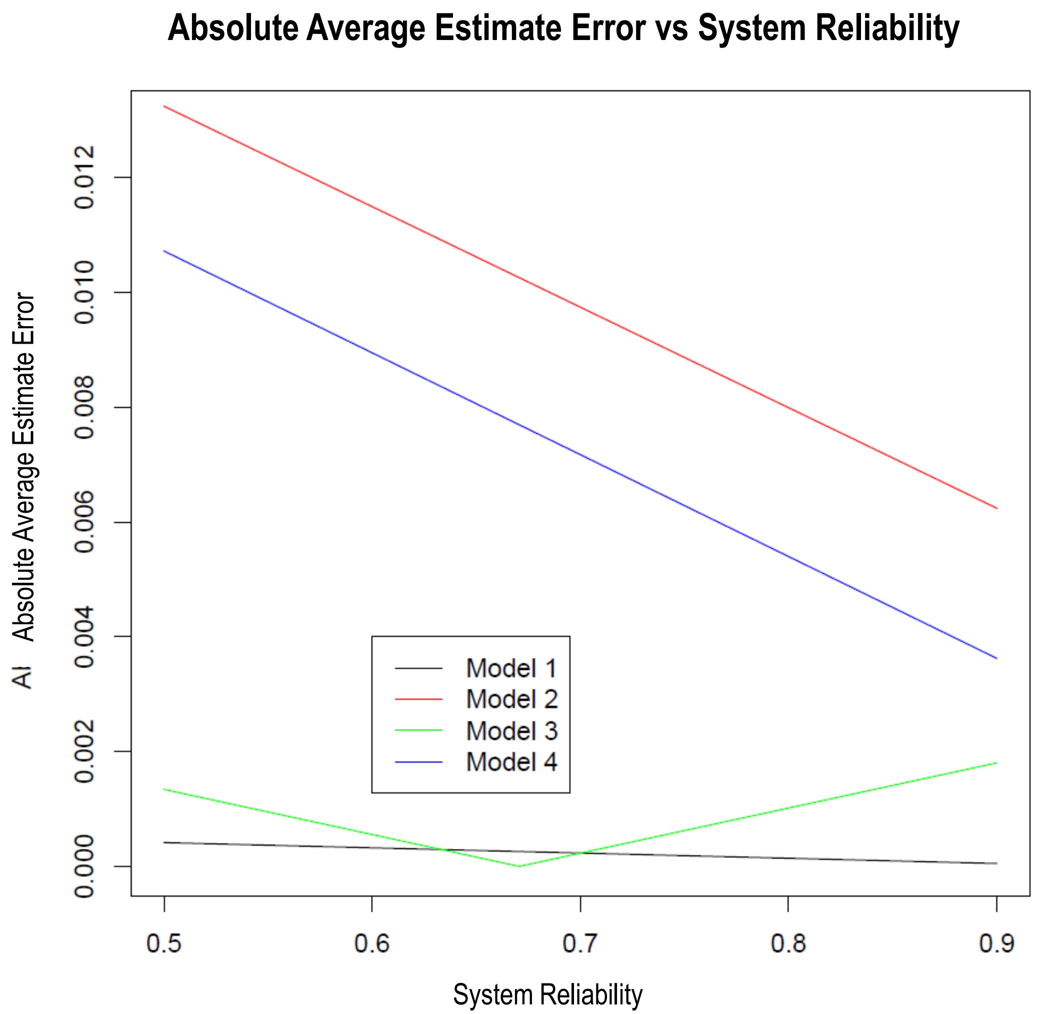
Number of types of tests	2 - 5
Number of tests	2 - 50
Ratio of live fire tests to total tests	$0.\overline{09}$ - $0.\overline{90}$
Number of components	30 - 45
Number of phases	1 - 3
True system reliability	0.5 - 0.9

Analysis

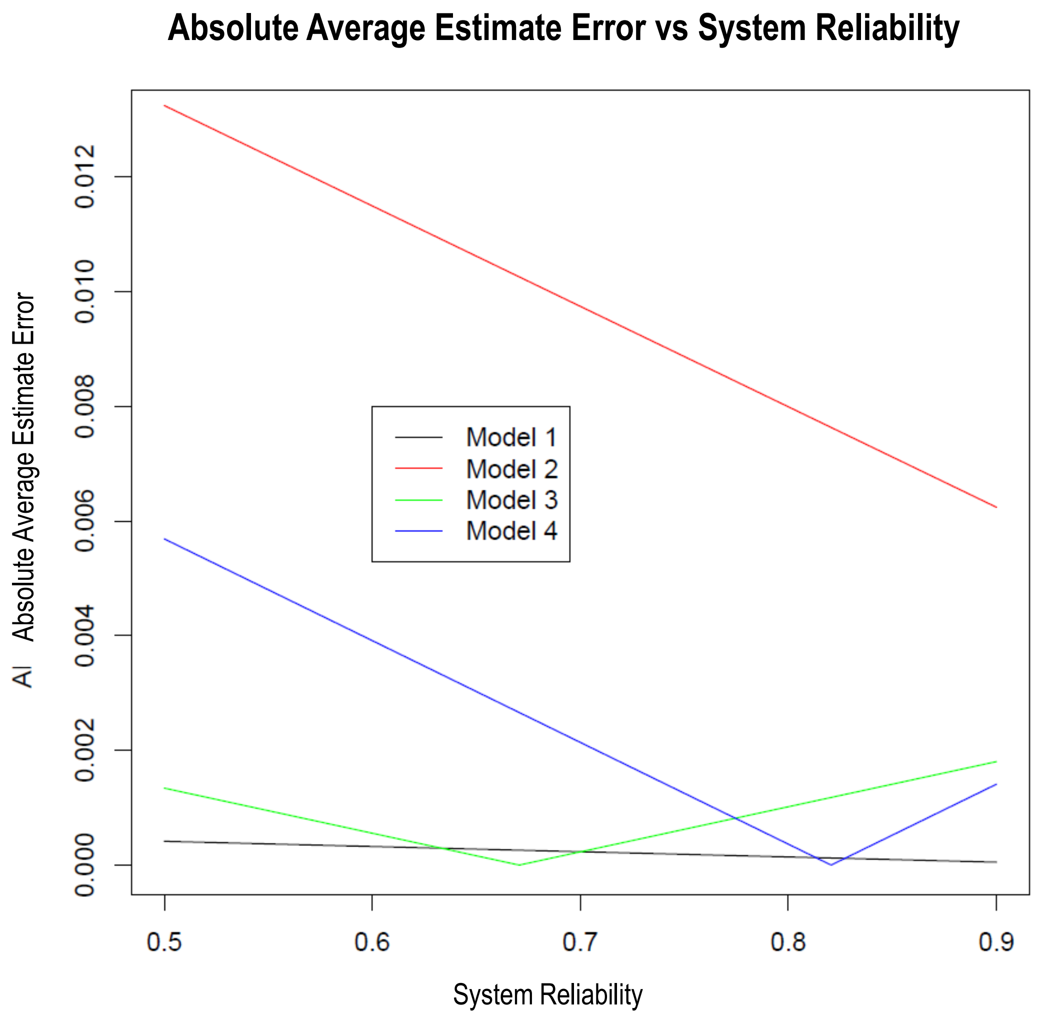
- **MANOVA indicates that all parameters except number of phases affect model selection**
- **Optimal model choice depends upon system under test**

```
> summary(model)
                            Df   Pillai    approx F   num Df   den Df   Pr(>F)
data$X..Types.of.Tests      1    0.05368   9.104      4        642      3.707e-07 ***
data$System.Reliability     1    0.64649   293.512    4        642      < 2.2e-16 ***
data$X..Tests               1    0.30713   71.145     4        642      < 2.2e-16 ***
data$Ratio.Live.Total       1    0.38682   101.251    4        642      < 2.2e-16 ***
Residuals           645
---
Signif. codes:  0  '***'  0.001 '**'  0.01 '*'  0.05 '.'  0.1 ' '  1
```

1 Phase, 2 Types of Test, 20 Tests
0.25 Ratio of Live Fire Testing to Total



1 Phase, 2 Types of Test, 20 Tests
0.75 Ratio of Live Fire Testing to Total



Summary

- Incorporating mixed data types can improve reliability estimates
- Model selection depends upon system under test
  - Simulation should be run for system under test
  - Simulation should be used for sensitivity analysis also

Questions

Questions?

Headquarters USAF Warfare Center

Testing - Tactics - Training

Mixed Data Type Exponential Smoothing For Reliability Prediction

Lt Jeremy L. Thompson

49 TES

30 January 2012

This Briefing is:

UNCLASSIFIED

Future Research

- Data transformation
- Confidence/prediction bands
  - Take into consideration varying confidence of annual reliability estimates

Headquarters USAF Warfare Center

Testing - Tactics - Training

Mixed Data Type Exponential Smoothing For Reliability Prediction

Lt Jeremy L. Thompson

49 TES

30 January 2012

This Briefing is:

UNCLASSIFIED