U.S. AIR FORCE

A MACRO-STOCHASTIC MODEL TO IMPROVE THE ACCURACY OF DoD LIFE CYCLE COST ESTIMATES

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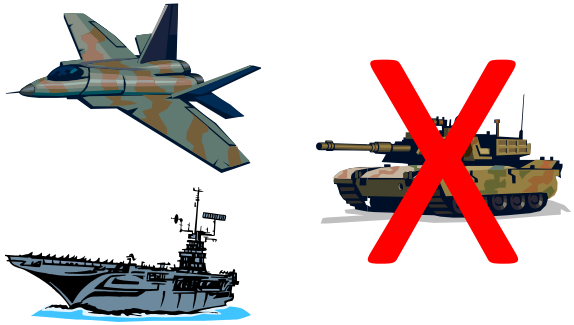
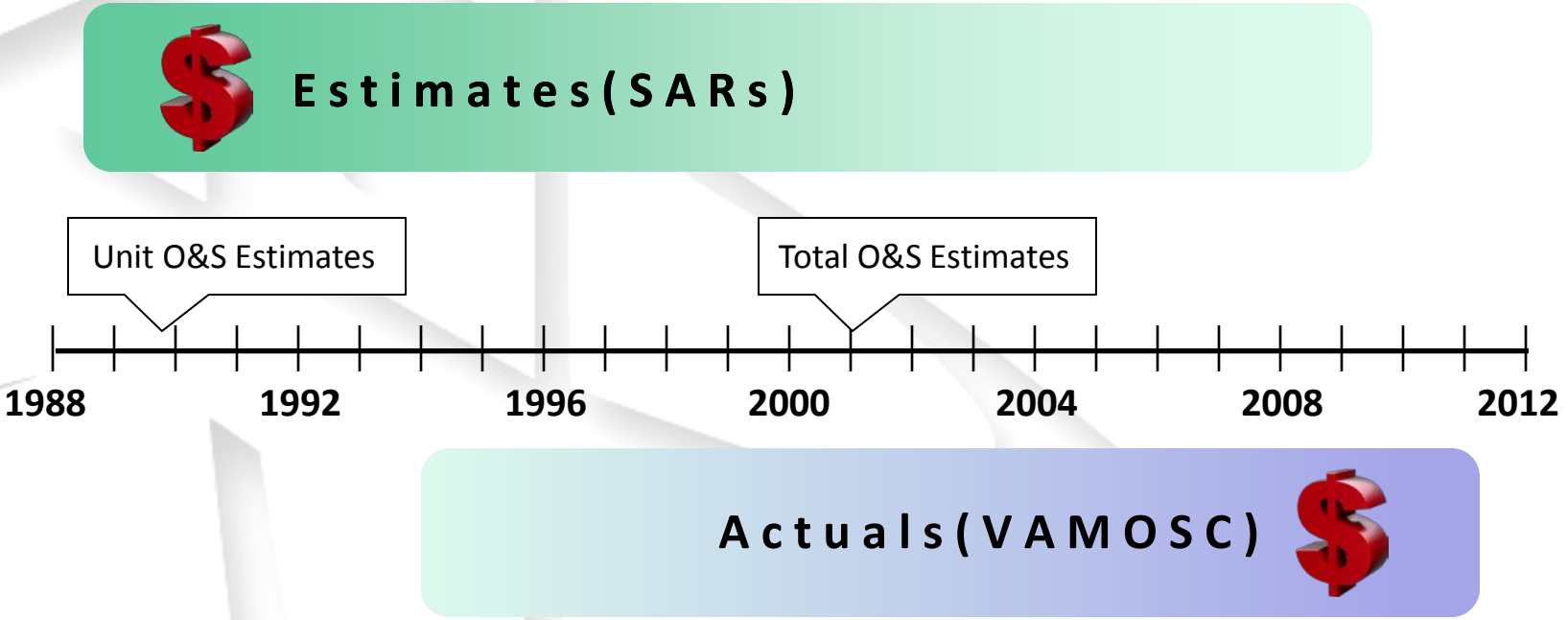
Agenda

- **Characterization Study**
- **Why are Estimates Poor?**
- **“Macro-Stochastic” Cost Estimating**
  - Theoretical Results
  - Validated Results
- **Caveats**
- **Now What?**

Methodology

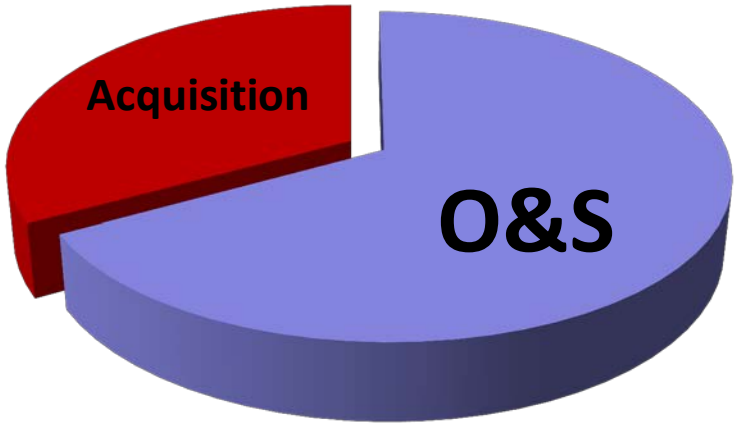
- **Three elements required**
  - Estimates, Actuals, and Elapsed Time
  - Predictions vs. “ground truth”





Definitions

- **O&S Cost**
  - Total cost to sustain weapon system after fielding
- **Annual Unit O&S Cost (AUC)**
  - Yearly cost to maintain per unit
- **Life Cycle Cost (LCC)**
  - Total cost to govt spanning all phases of the program's life
    - Development, procurement, operation, sustainment, & disposal
  - Essentially LCC = Total Acq Costs + Total O&S Costs



O&S Costs comprise 60-75% of Life Cycle Costs*

Key Findings

- **Accuracy of O&S-based cost estimates is poor and improves little over time**
  - AUC Estimates
    - Magnitude of mean errors ~40%; reduces ~1% per year on average
  - LCC Estimates
    - Magnitude of mean errors ~20%; reduces ~1.5% per year on average
- **O&S-based cost estimates behave differently than acquisition cost estimates**
  - Greater levels of inaccuracy; do not converge
- **Decision Analysis**
  - Validity of value decisions based on AUC/LCC estimates?

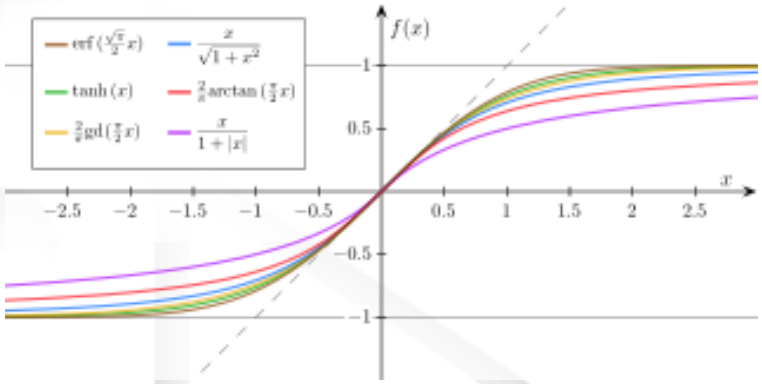
More Key Findings

- **Many other elements of a program have significant relationship with estimate accuracy**
  - Type of system
  - Size of acquisition effort
  - Procurement Quantity
  - Cost Variance Trends

Opportunity to improve cost estimating…

Why Are Estimates Poor?

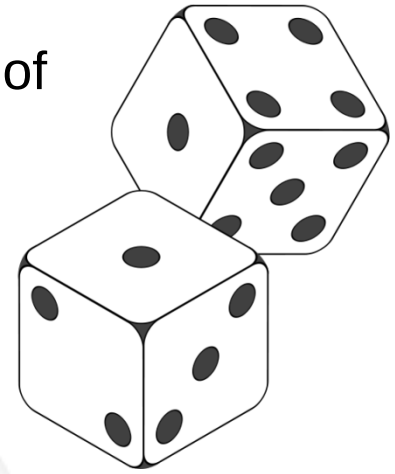
- **Many sophisticated cost estimating techniques**
  - e.g., probability distributions, confidence intervals, s-curves, Monte Carlo simulations, and sensitivity analyses



- **All assume a fixed baseline**
  - APB deviations are virtually inevitable
  - Link to APB represents flaw in current estimate process

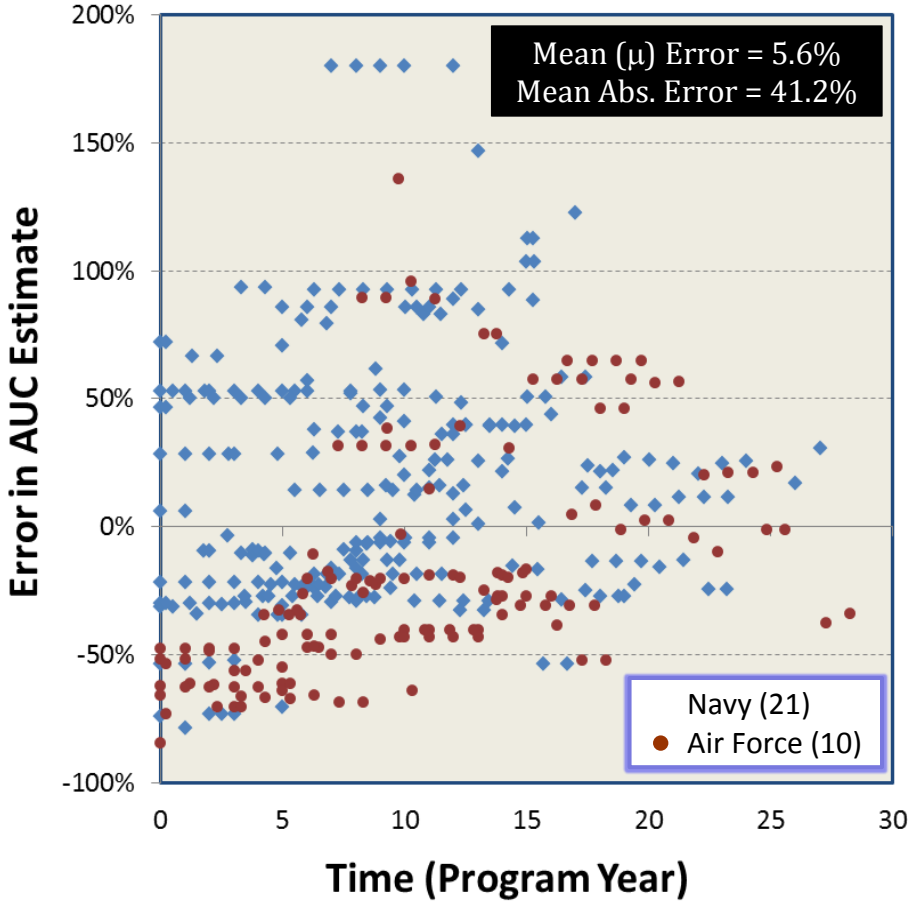
Are Estimate Errors Random?

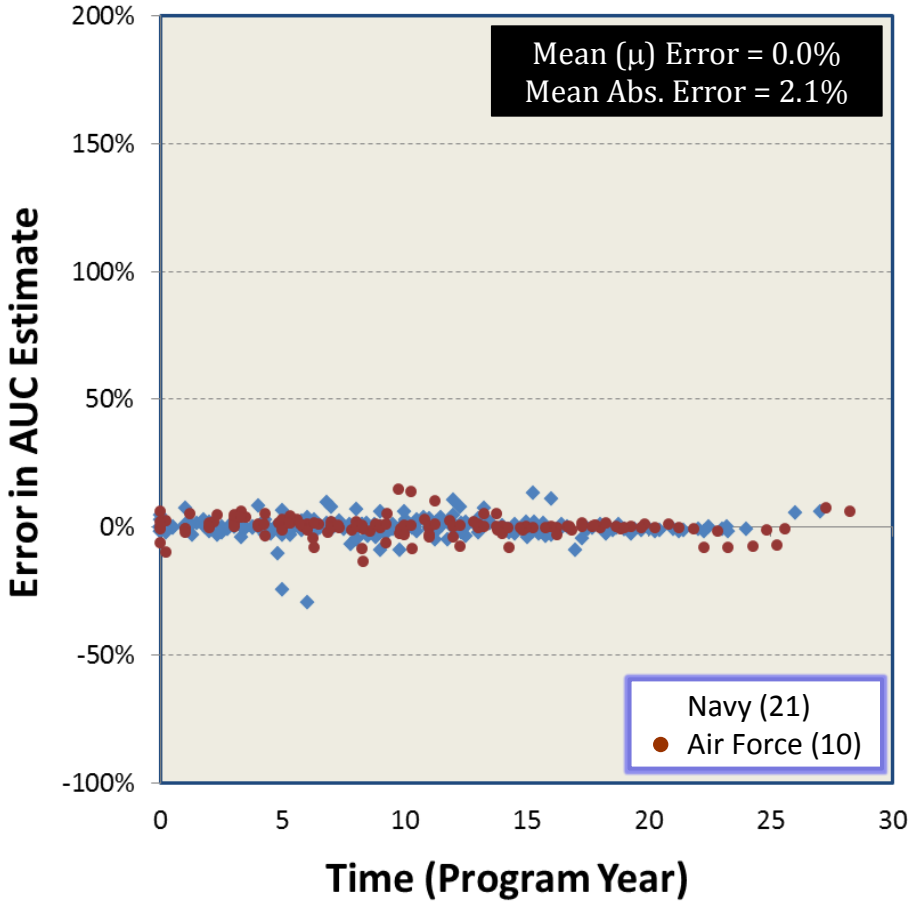
- **Need alternate cost estimating methodology**
- **Treat estimate error as a stochastic variable**
  - Examine top-level program summary indicators
    - e.g., Service component, type of system, program size, program maturity, prime contractor, breach patterns, cost variance trends, procurement quantities, reqmnt trends
  - "Macro-stochastic" cost estimation
  - Can certain variables serve as effective predictors of estimate errors?



AUC Macro-Stochastic Model

The AFIT of Today is the Air Force of Tomorrow



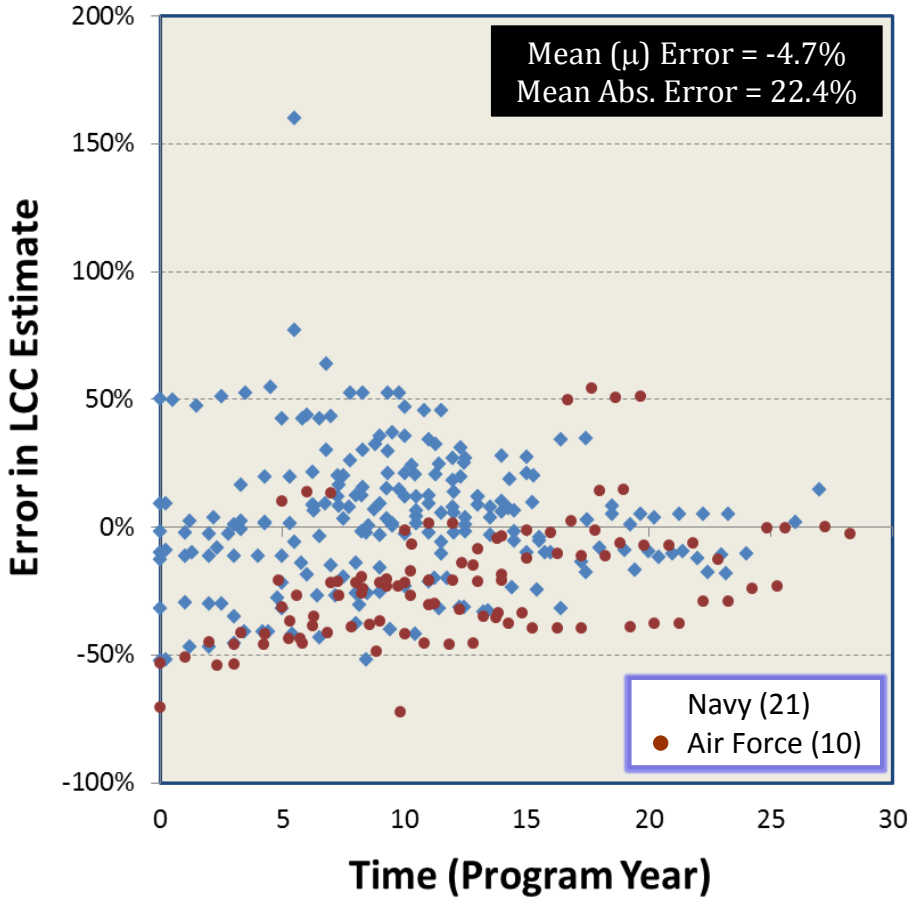


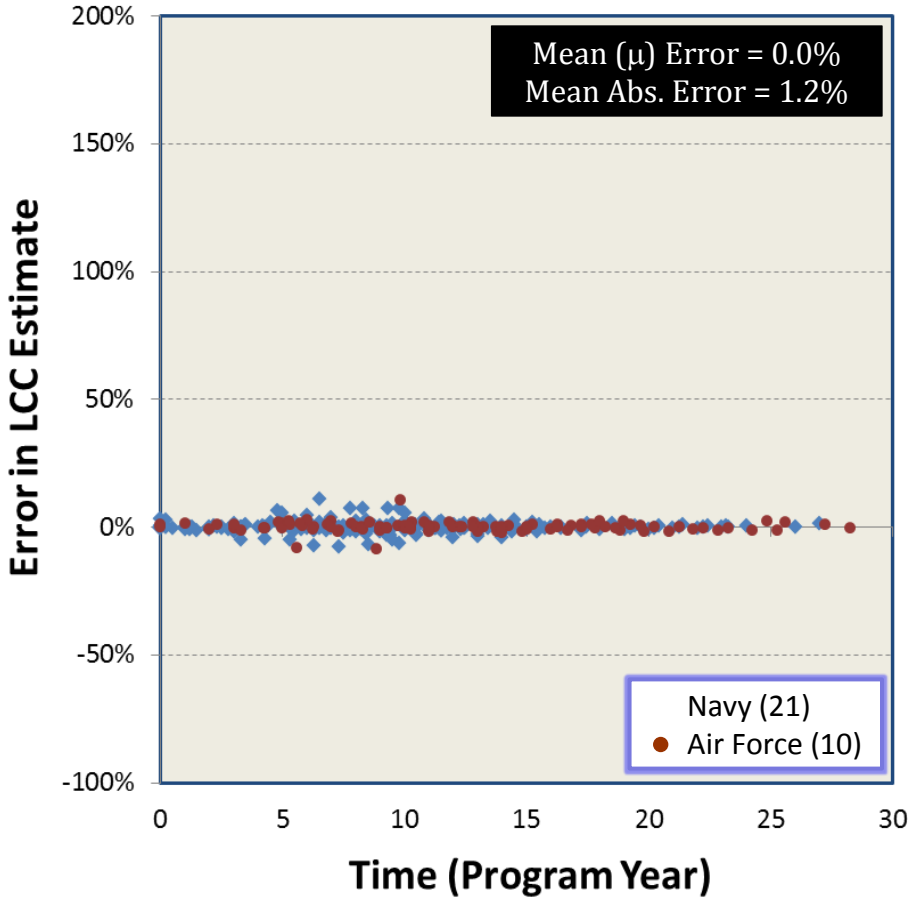
Empirical Data
32% of estimates within 25%

Model Corrected (Theoretical)
99.7% of estimates within 25%

LCC Macro-Stochastic Model

The AFIT of Today is the Air Force of Tomorrow



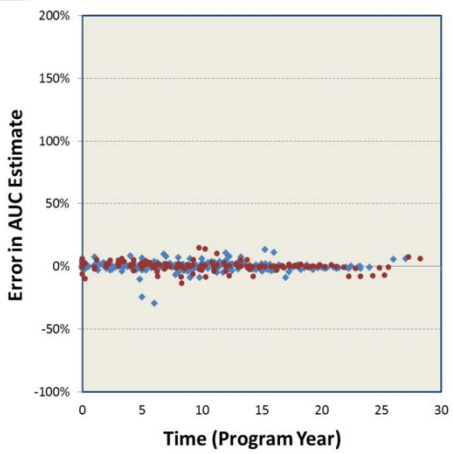


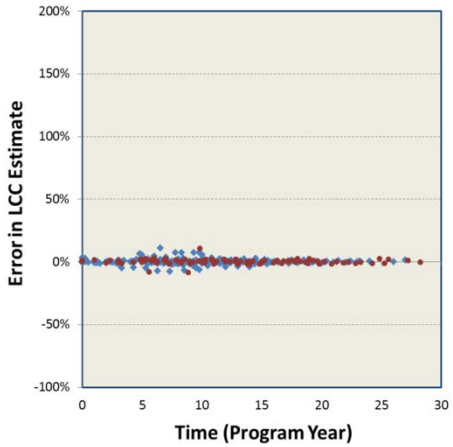
Empirical Data
62% of estimates within 25%

Model Corrected (Theoretical)
100.0% of estimates within 25%

Estimate Errors are Random

- **Strong Pattern of Estimating Errors**
  - Each program has its own pattern
  - Just 3 variables
    - Change in procurement quantity
    - Current acq cost estimate
    - Current LCC estimate
- **Estimate Errors are Random**
  - However…





Making the Model Useful

- **Theoretical model not useful for prediction**
  - Takes too long to identify specific pattern
- **Strategy to make the model capable of prediction**
  - Program Categories
  - “Market sector”
  - DoD component, type of system, size of program

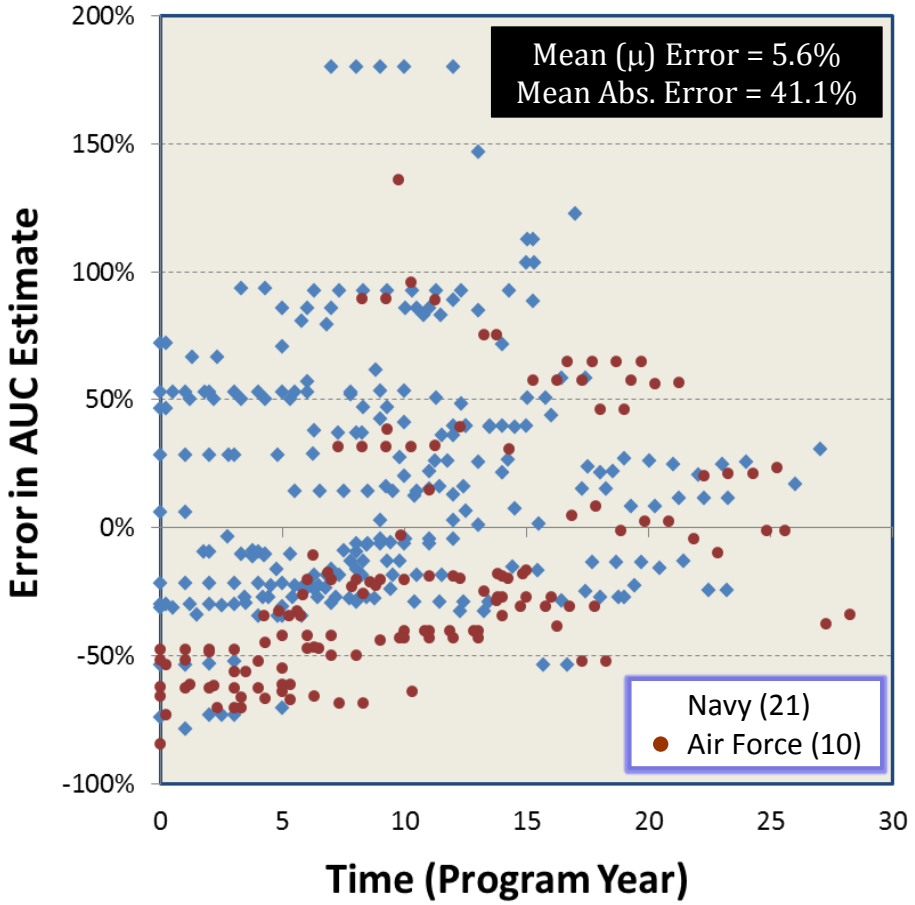
Program Categories

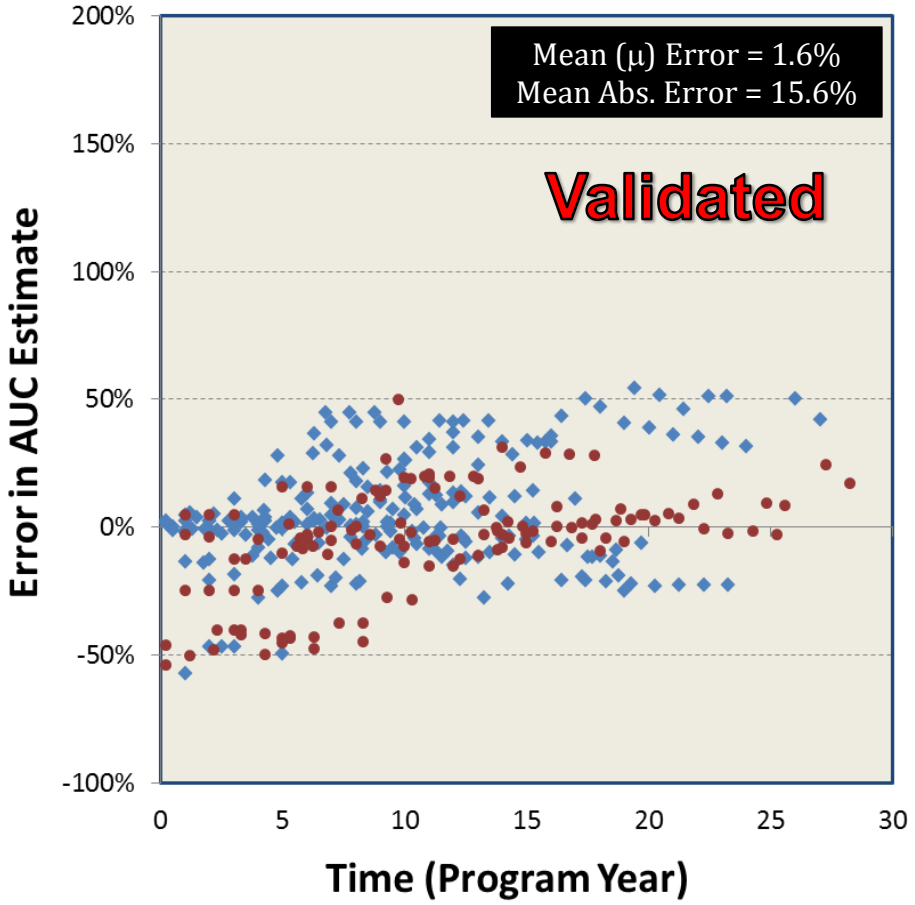
PCat	DoD Comp	System Type	Size (Mean Acq Cost Est, BY10)
1	AF	Aviation	Small (≤ $18.0B)
2	Navy	Aviation	Small (≤ $18.0B)
3	Both	Aviation	Large (> $18.0B)
4	Navy	Maritime	Small (≤ $8.5B)
5	Navy	Maritime	Medium ($8.5B – $30.0B)
6	Navy	Maritime	Large (> $30.0B)
7	Both	Munition	All
			TOTALS

Model Variables

LCC	AUC
DoD Component	DoD Component
Acquisition Type	Acquisition Type
Acquisition Cost Estimate	Acquisition Cost Estimate
Nunn-McCurdy Breach	Acquisition Phase
Procurement Quantity Change	Procurement Quantity Change
	Planned Procurement Quantity
LCC Estimate	AUC Estimate
Cost Variance, Estimating	Cost Variance, Estimating
Cost Variance, Quantity	Cost Variance, Quantity
	Cost Variance, Engineering
Cost Variance, Total	Cost Variance, Total

AUC Model Performance

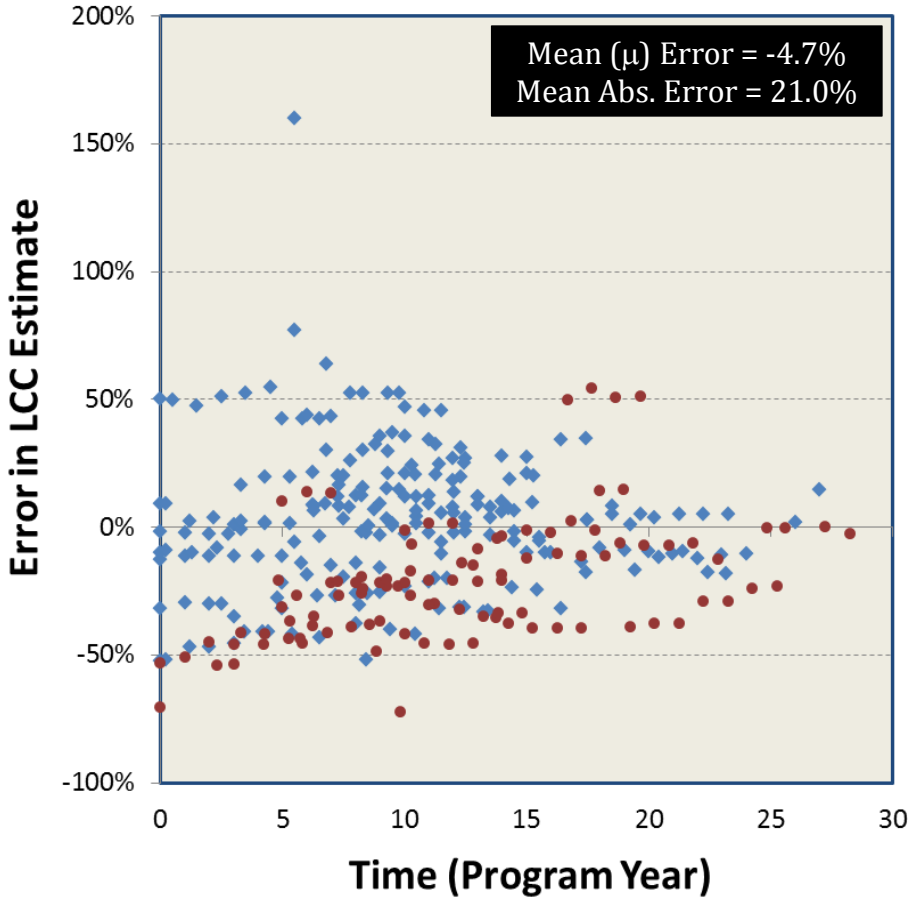


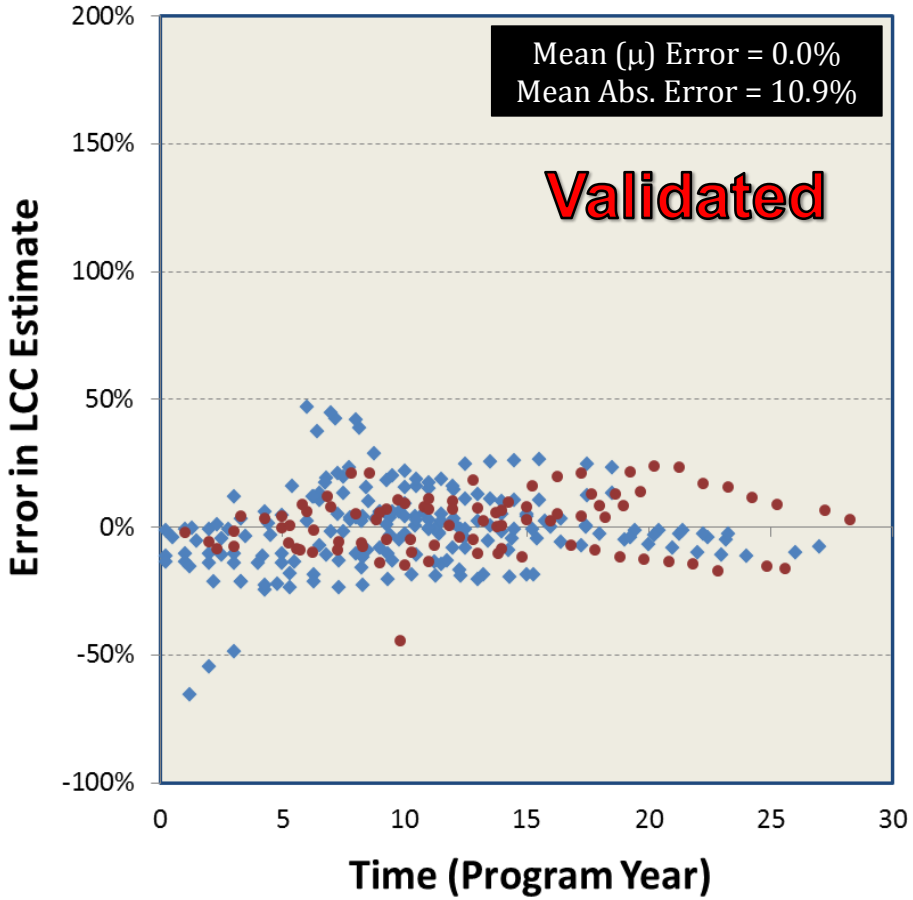


Empirical Data
32% of estimates within 25%

Model Corrected (Validated)
70% of estimates within 25%

LCC Model Performance



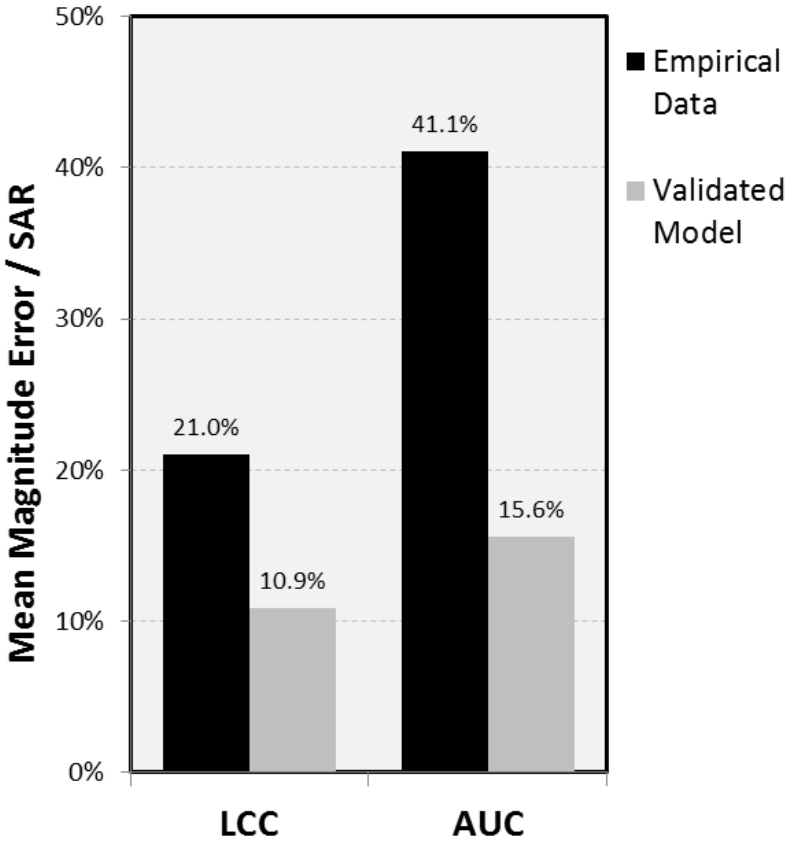


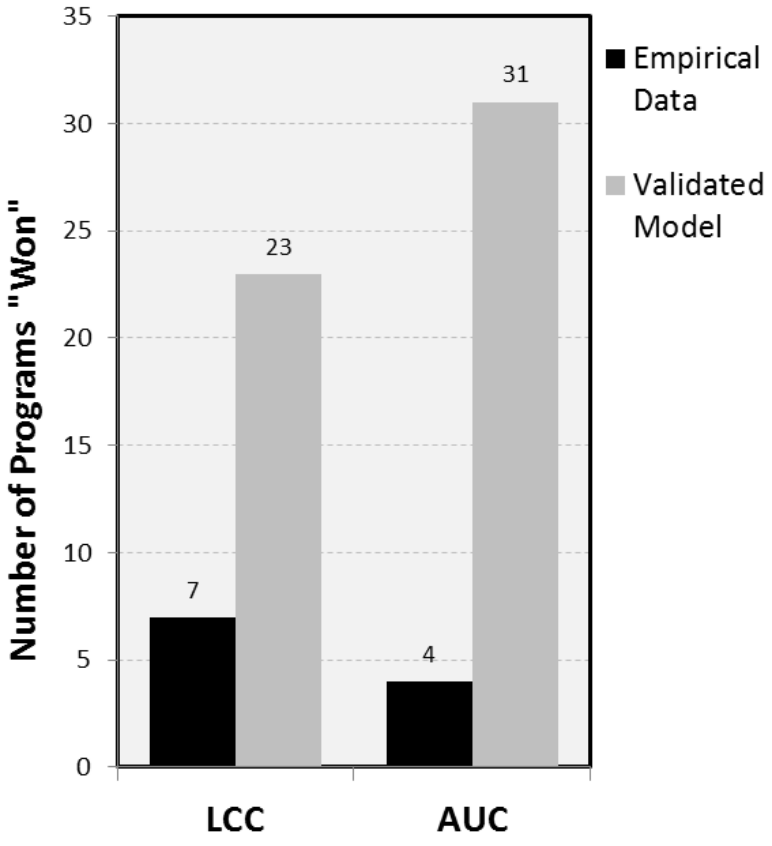
Empirical Data
62% of estimates within 25%

Model Corrected (Validated)
95% of estimates within 25%

A Better Cost Estimating Model

The AFIT of Today is the Air Force of Tomorrow





Average estimating improvement: $2.6B/program

Macro-Stochastic Model Summary

- **Significant Improvement in Accuracy**
  - Magnitude and variability of average errors reduced 50-60%
  - Improves expected estimate fidelity by tens of billions of dollars
- **Minimal Effort**
  - Model-derived correction factor available in hours
- **Model validity independent of characterization study**
  - Characterization study results inform model parameters

Certain types and degrees of change in certain types of programs do tend to affect the accuracy of the current cost estimates in relatively predictable ways

Model Caveats

- **Validity assumes future programs like past programs**
  - Programs must “fit” into one of the program categories
  - More programs needed to fill out categories
- **Applicability limited by source data**
  - MDAPs
  - AF and Navy
  - Post MS-B
  - Aviation, Maritime, and Munitions
- **Requires at least one previous SAR**
- **Not independent; modifies program estimate**
  - Probabilistic indication of where program costs are likely to end up
- **Non-transparent**

Now What?

- **Implementation**
  - Outside acq chain of command
    - OSD/CAPE
    - DAE/DAB
    - Portfolio Manager
- **Future Work**
  - Expand the data set
    - Include more recent data
    - Non-MDAPs
    - Pre MS-B
  - Make independent
  - Have output value be a distribution

Summary

- **O&S cost estimates are very poor and improve little**
- **Cost estimators not the problem**
  - *Assumption of static APB* is the problem
- **Patterns exist in estimate accuracy**
- **Nature of patterns can be characterized**
- **Embrace Uncertainty!**
  - An otherwise “perfect” cost estimate constrained by today’s baseline is bound to be wrong tomorrow
  - Decision makers need an estimate that accounts for uncertainty

More Information

- **"A Macro-Stochastic Model for Improving the Accuracy of DoD Life Cycle Cost Estimates"**
  - *Journal of Cost Analysis and Parametrics*
- **"Characterizing the Accuracy of DoD Operating and Support Cost Estimates"**
  - *Journal of Public Procurement*
- **"A Proposed Methodology to Characterize the Accuracy of Life Cycle Cost Estimates for DoD Programs"**
  - *Procedia Computer Science*

BACKUPS

Independent Variables

Program Year	DoD Component	Joint
System Type	Acquisition Phase	Acquisition Type
Maturity	APB Changes	Funding Years
Prime Contractor	Acquisition Cost Estimate	AUC Estimate
O&S Cost Estimate	LCC Estimate	% Expended
PAUC	APUC	Cost Variance, Total
Cost Variance, Engr	Cost Variance, Est	Cots Variance, Quan
Cost Breaches	Tech. Perf. Breaches	Schedule Breaches
Unit Cost Breaches	Nunn-McCurdy Breaches	Procurement Quantity
CDR	PDR	MSII
LRIP	MSIII	IOC
New Reqmnts	Deleted Reqmnts	Reqmnt Changes

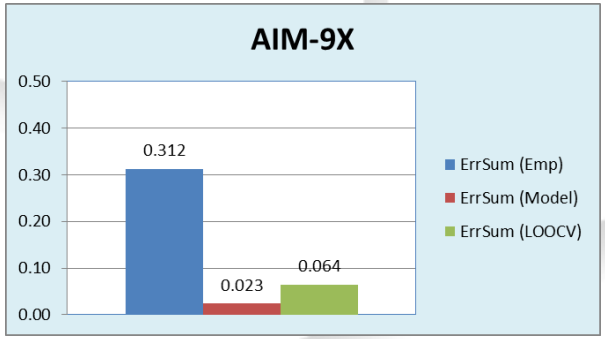
AUC PCats

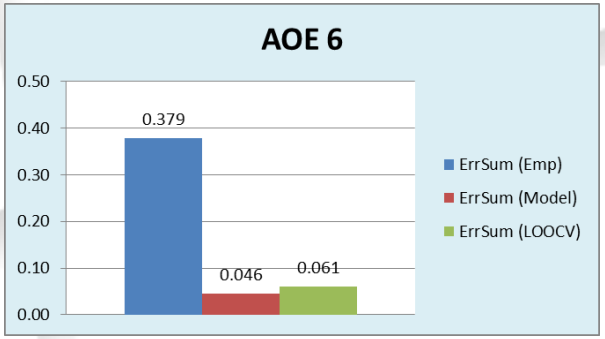
PCat	DoD Comp	System Type	Size (Mean Acq Cost Est, BY10)	SARs	# of Programs	Assigned Programs
1	AF	Aviation	Small (≤ $18.0B)	58	5	C-130J, GLOBAL HAWK, KC-135A, JPATS, JSTARS
2	Navy	Aviation	Small (≤ $18.0B)	68	6	AV-8B, C/MH-53E, E-2C, MH-60R, MH-60S, T-45TS
3	Both	Aviation	Large (> $18.0B)	83	6	C-17A, F-16C/D, F-22, F-14D, F/A-18C, F/A-18E/F
4	Navy	Maritime	Small (≤ $8.5B)	52	8	AOE 6, CVN68 (74/75), CVN68 (76), MHC 51, SSGN, STRAT. SEALIFT, T-AKE, T-AO 187
5	Navy	Maritime	Medium ($8.5B – $30.0B)	42	3	LHD 1, LPD 17, SSN 21
6	Navy	Maritime	Large (> $30.0B)	36	2	DDG 51, SSN 774
7	Both	Munition	All	53	5	AIM-9X, AMRAAM-AF, AMRAAM-JT, JASSM, JSOW
			TOTALS	**392**	**35**	

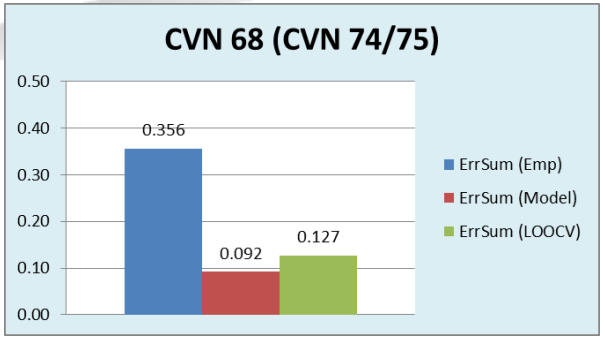
LCC PCats

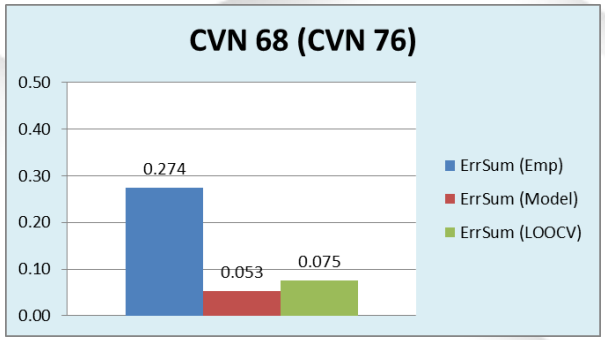
PCat	DoD Comp	System Type	Size (Mean Acq Cost Est, BY10)	SARs	# of Programs	Assigned Programs
1	AF	Aviation	Small (≤ $18.0B)	33	4	C-130J, JPATS, JSTARS, PREDATOR
2	Navy	Aviation	Small (≤ $18.0B)	53	5	C/MH-53E, E-2C, MH-60R, MH-60S, T-45TS
3	Both	Aviation	Large (> $18.0B)	60	5	C-17A, F-16C/D, F-22, F-14D, F/A-18E/F
4	Navy	Maritime	Small (≤ $8.5B)	41	7	AOE 6, CVN68 (74/75), CVN68 (76), MHC 51, SSGN, T-AKE, T-AO 187
5	Navy	Maritime	Medium ($8.5B – $30.0B)	42	3	LHD 1, LPD 17, SSN 21
6	Navy	Maritime	Large (> $30.0B)	36	2	DDG 51, SSN 774
7	Both	Munition	All	52	5	AIM-9X, AMRAAM-AF, AMRAAM-JT, JASSM, JSOW
			TOTALS	**317**	**31**	

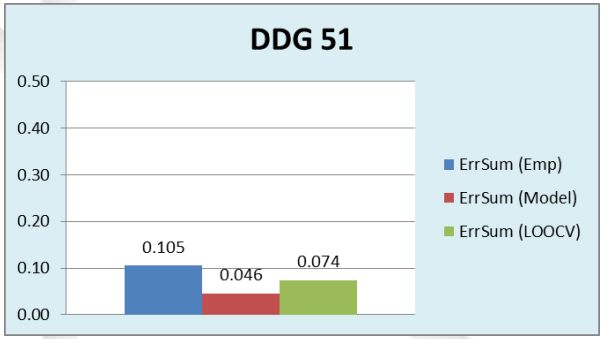
LCC Model by Program

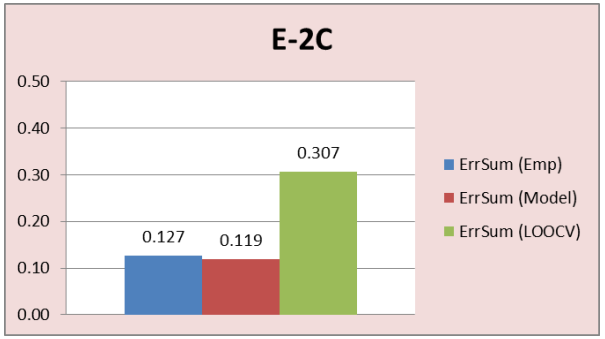


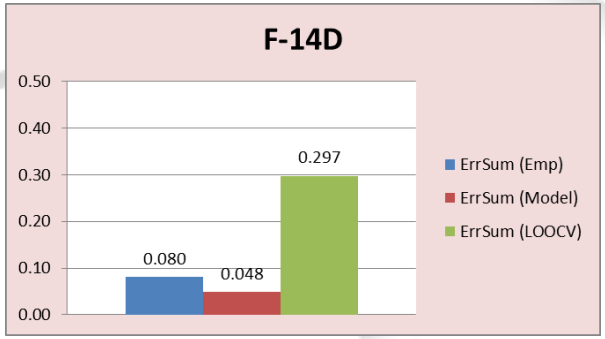


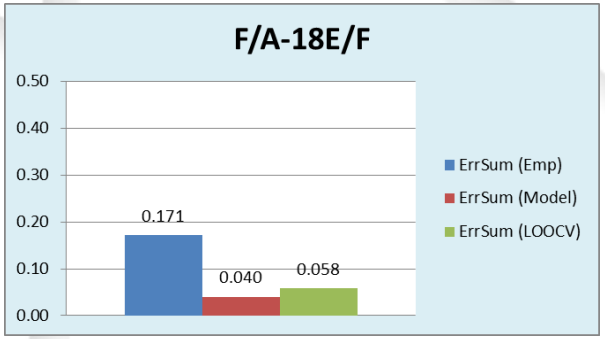


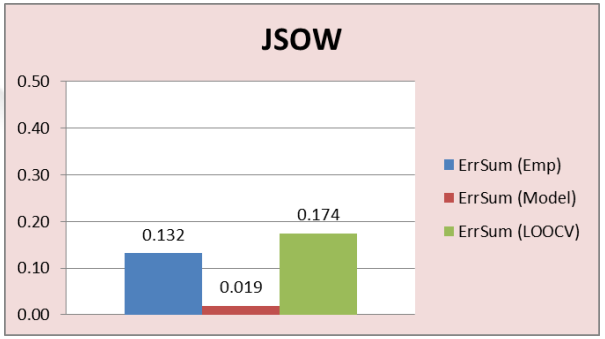






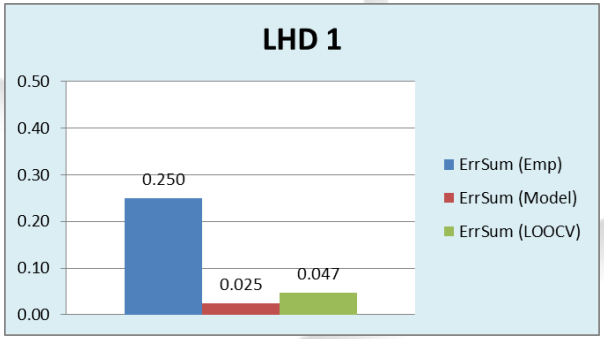


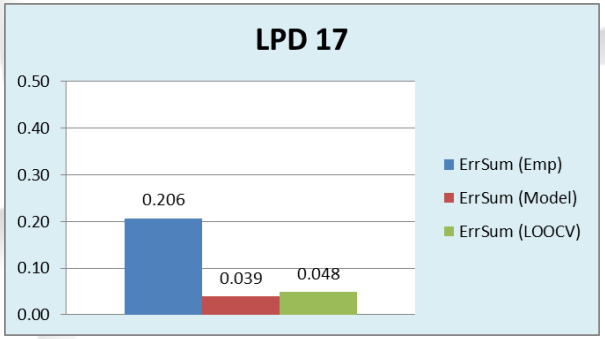


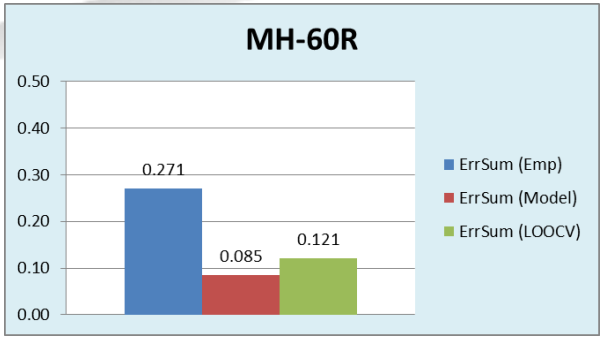


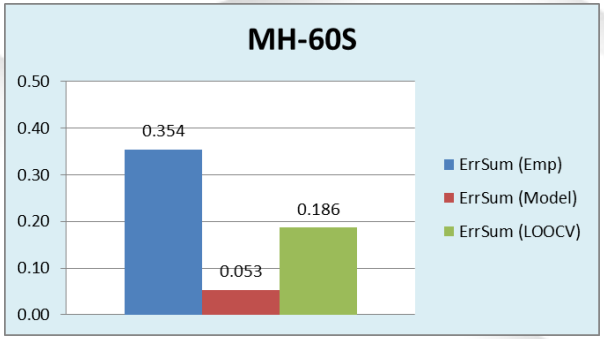
LCC Model by Program

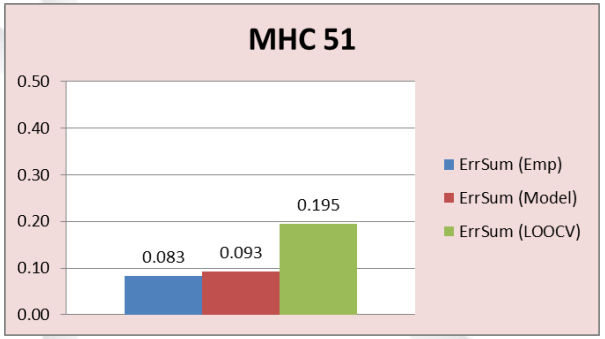
The AFIT of Today is the Air Force of Tomorrow

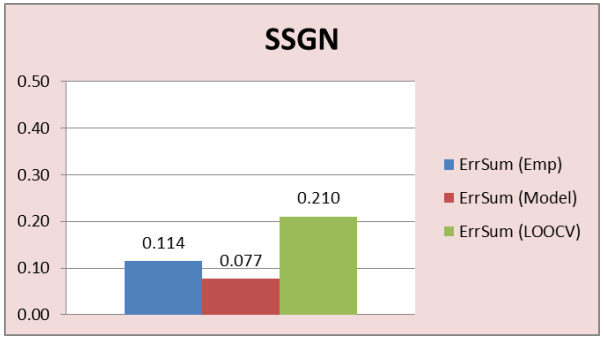


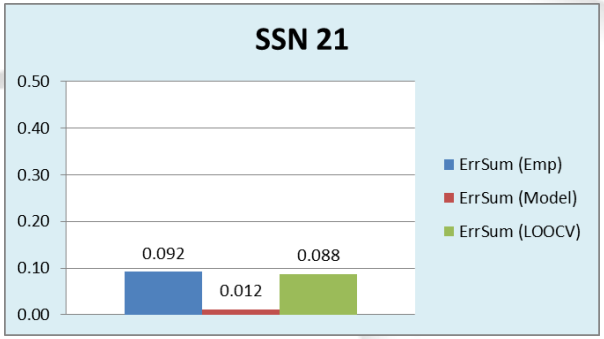


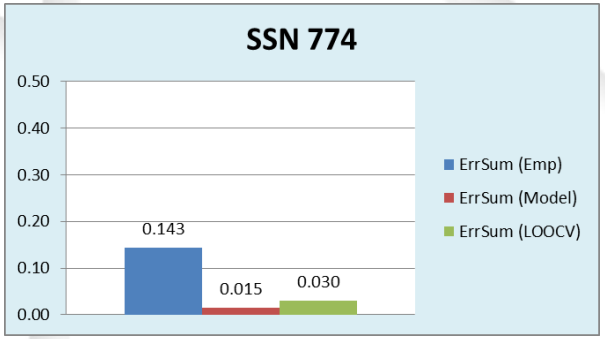


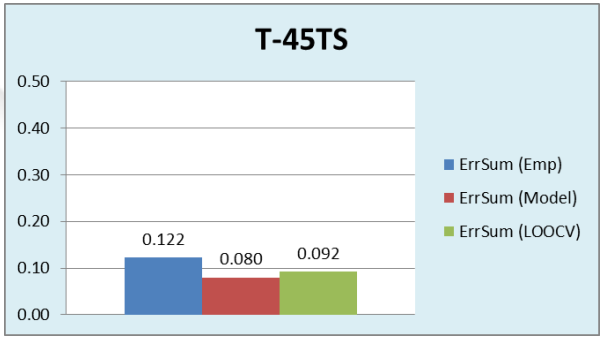




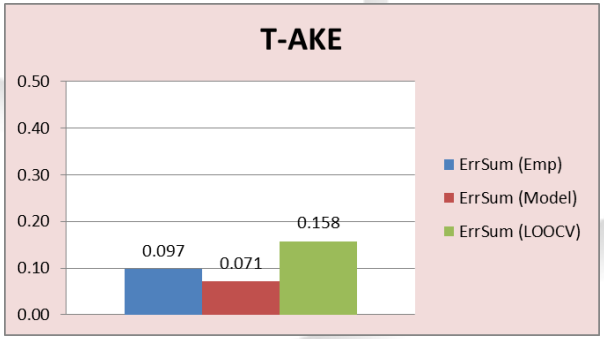


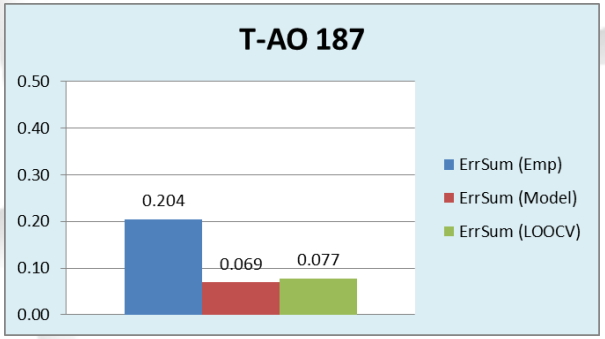


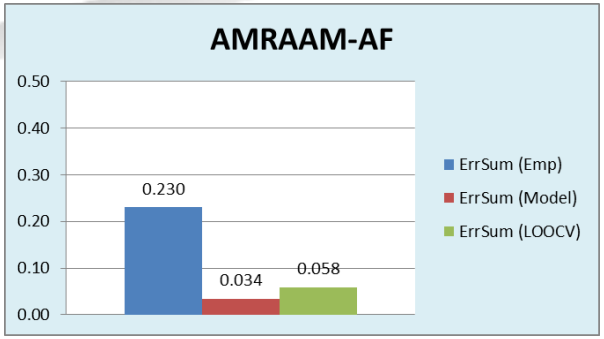


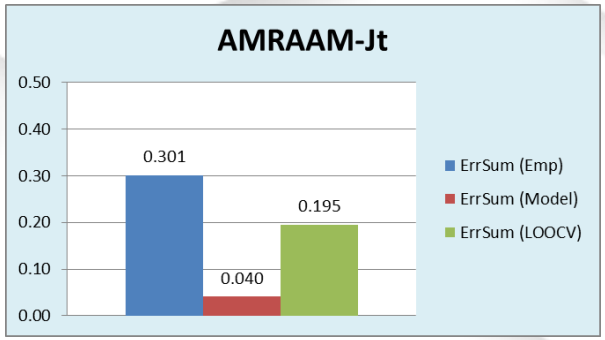


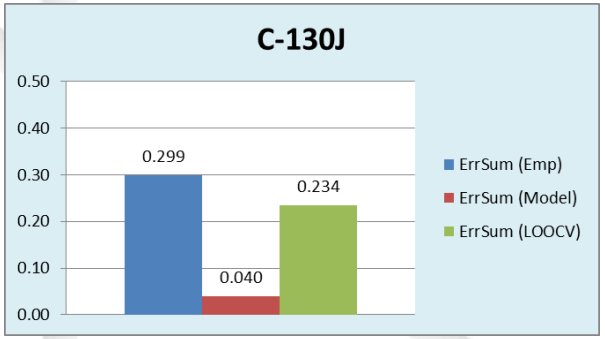
LCC Model by Program

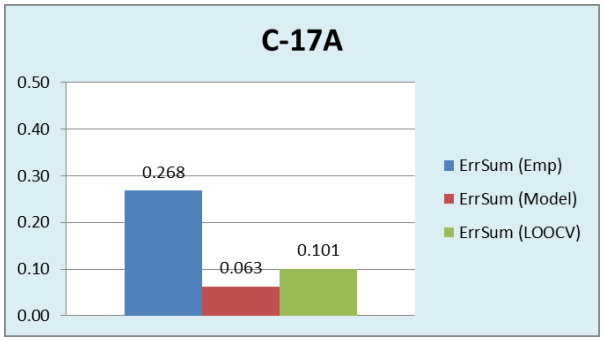


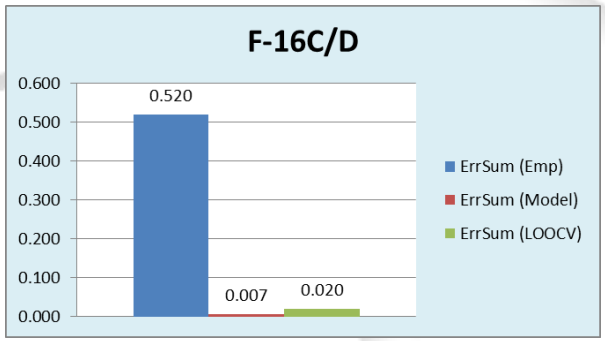


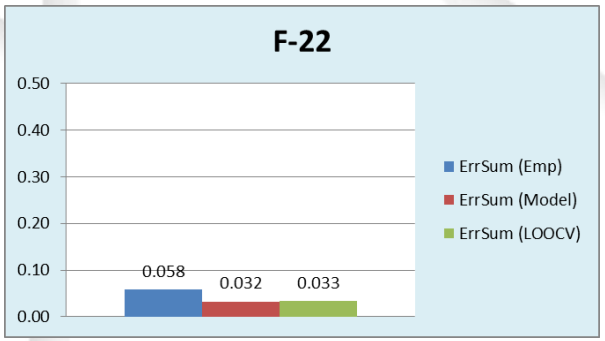


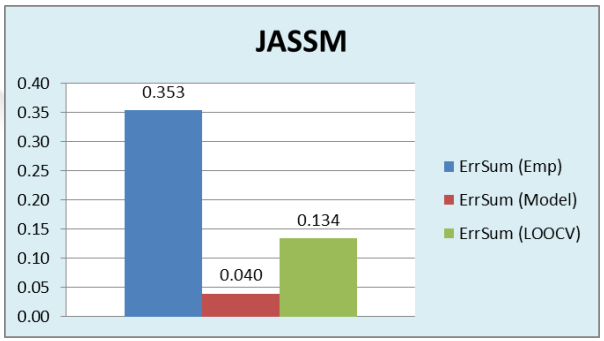




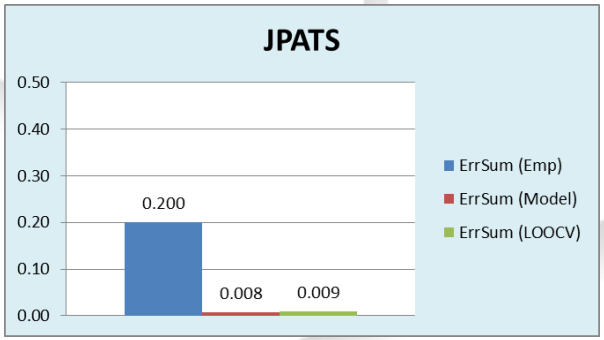


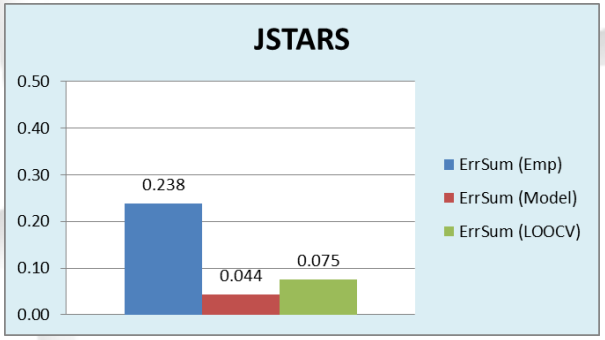


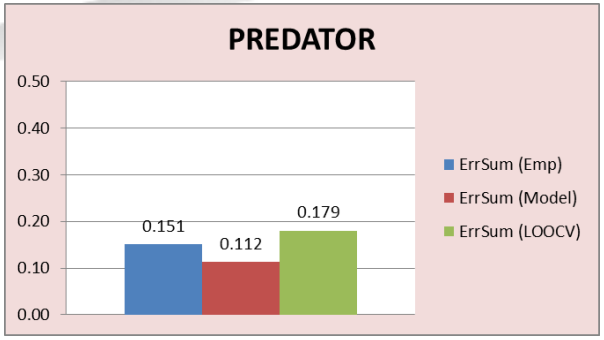


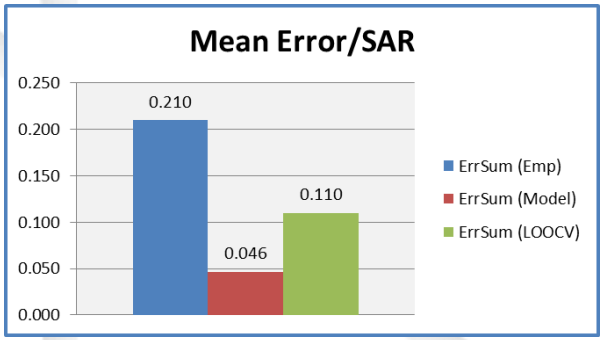


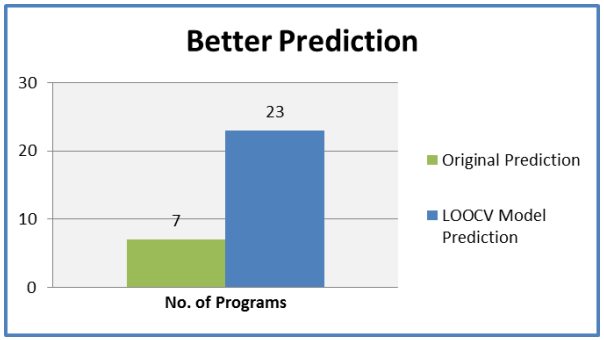
LCC Model by Program











Mixed Models

- **Mixed models compensate for correlated errors**
  - Can account for subject observations not independent
  - Allow data to exhibit inherent correlations and non-constant variability that arise from the data hierarchy
  - Some regression parameters are population-specific (fixed-effects)
  - Other parameters are subject-specific (random-effects)

$$y = X\beta + Z\gamma + \varepsilon$$

y = Observed data vector
X = Fixed-Effect Design Matrix
β = Vector of Fixed-Effect Parameter Estimates (same for all subjects)
Z = Random-Effect Design Matrix
γ = Vector of Random-Effect Parameter Estimates (varies by subject)
ε = Vector of Residual Errors