Enhanced Scenario-Based Method for Cost Risk Analysis: Theory, Application, and Implementation

2012 SCEA/ISPA Joint Annual Conference and Training Workshop

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In memory of Dr. Steve Book, nulli secundus, for his kindness and devotion, and for his invaluable comments and insights on our paper.

Contents

eSBM: Background

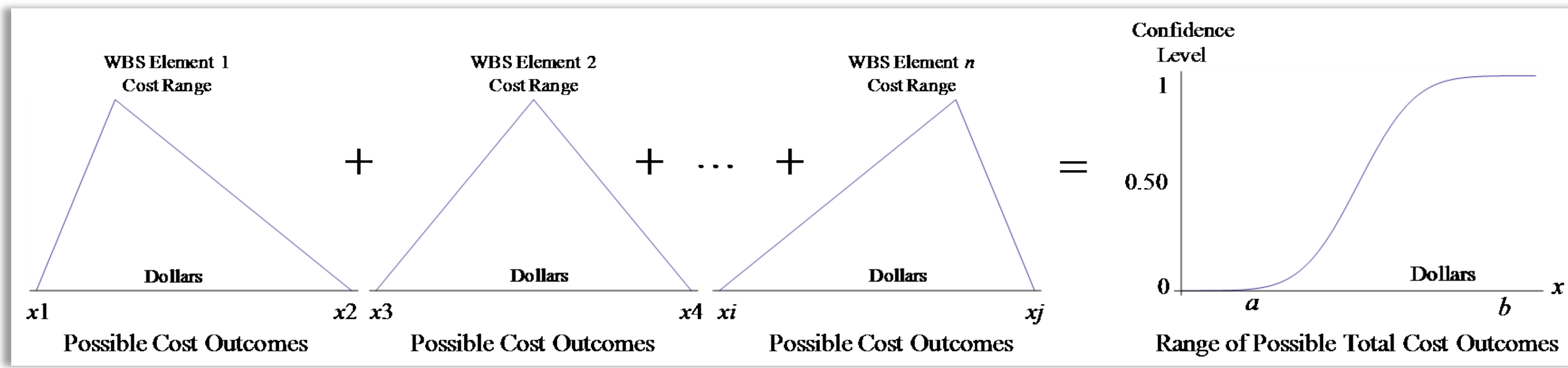
- Scenario-Based Method* (SBM) introduced in 2006
  - Alternative to advanced statistical methods for cost risk analysis
  - Two modes
    - Without statistics
    - With statistics, but without reliance on Monte Carlo Simulation
- Weapon System Acquisition Reform Act (WSARA) of 2009
  - Requirement for statement of confidence in cost estimate
    - Increased emphasis on the statistical mode of SBM
  - Enhanced SBM (eSBM)**
    - Integrating historical cost results in SBM's equations
    - Providing context for applying SBM from a WSARA perspective

*"A Scenario-Based Method for Cost Risk Analysis," Garvey; *Journal of Cost Analysis and Parametrics*, Vol. 1, 2008.
**"Enhanced Scenario-Based Method (eSBM) for Cost Risk Analysis," Garvey; DODCAS 2011

eSBM

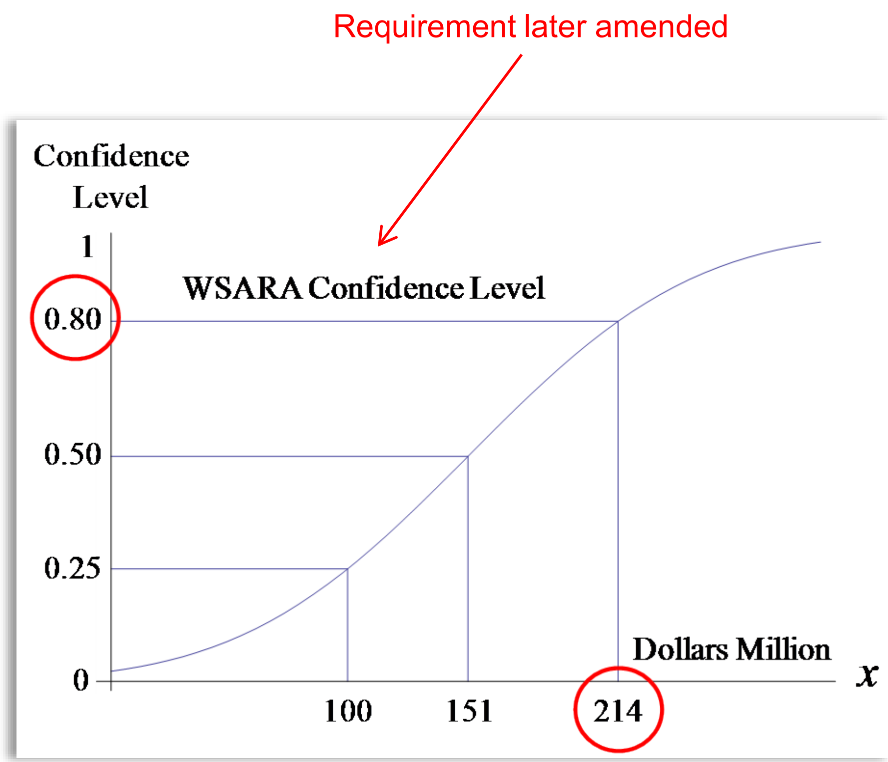
- WSARA: Public Law 111-23, Section 101 states:
  - *The Director [CAPE] shall … issue guidance relating to the proper selection of confidence levels in cost estimates generally, and specifically, for the proper selection of confidence levels in cost estimates for major defense acquisition programs and major automated information system programs*

- Probability theory ideal for deriving measures of confidence
  - Program's cost can be treated as an uncertain variable



eSBM

- Cumulative probability distribution of a program's acquisition cost
  - Cost estimate confidence is read from this distribution
  - For example
    - 25 percent chance the program will cost <= $100M
    - 50 percent chance the program will cost <= $151M
    - 80 percent chance the program will cost <= $214M



eSBM Analytical Work Flow

These top steps are the same as the non-statistical SBM process

Start

Input: Program's Point Estimate Cost (PE)

Input: Select Probability PE Will Not be Exceeded; see Historical Data Guidelines

$= \alpha_{PE}$

Input: Select Appropriate Coefficient of Dispersion (CV) Value From Historical Data Guidelines

Define Protect Scenario (PS)

Accept PS

Reject PS

Iterate/Refine PS

Compute PS Cost and Cost Reserve CR, where CR = PS Cost – PE

Accept CR

Reject CR

Iterate/Refine PS Cost

End

Conduct Sensitivity Analysis of Results and Report Out

Confidence Level Determinations

Use this Distribution to View the Confidence Level of the PS Cost

Derive Program's Cumulative Probability Distribution From Selected α_{PE} and CV

These bottom steps are specific to the statistical SBM process

Notation: In statistics, the coefficient of variation is often abbreviated as COV or CV; this statistic is also known as the coefficient of determination (COD)

eSBM Scenarios

- Definition of scenario
  - "Sequence of events; an account or synopsis of a possible course of action or outcome expected from possible events" (Merriam-Webster)
- eSBM scenarios
  - Unfavorable: →costs higher than the level planned or budgeted
  - Set of coherent conditions to guard against
    - Not worst cases
  - Articulates a risk-adjusted cost position
    - Tightly coupled with
      - Cost Analysis Requirements Document
      - Systems engineering plan (SEP)
      - Acquisition strategy document
      - ICD and other requirements' documents
    - Source documents form the basis for the integrity of scenarios developed by the program, its participants, and its stakeholders

eSBM Inputs

- eSBM needs only 3 inputs

1 2 3

The eSBM needs only three inputs. These are the point estimate cost, the probability PE cost will not be exceeded, and the coefficient of variation. The probability PE cost x_{PE} will not be exceeded is the value α_{PE}, such that

$$P(Cost_{Pgm} \leq x_{PE}) = \alpha_{PE} \qquad (1)$$

In Equation 1, $Cost_{Pgm}$ is the true but uncertain total cost of the program and x_{PE} is the program's point estimate cost. The probability α_{PE} is a judged value guided by experience that it typically falls in the interval $0.10 \leq \alpha_{PE} \leq 0.50$. This interval reflects the understanding that a program's point estimate usually faces higher, not lower, probabilities of being exceeded.

The coefficient of variation (CV) is the ratio of a probability distribution's standard deviation to its mean. This ratio is given by Equation 2. The CV is a way to examine the variability of any distribution at plus or minus one standard deviation around its mean.

$$CV = D = \frac{\sigma}{\mu} \qquad (2)$$

With values assessed for α_{PE} and CV, the program's cumulative cost probability distribution can then be derived. This distribution is used to view the confidence level associated with the PS cost, as well as confidence levels associated with any other cost outcome along this distribution.

eSBM Equations

- For normal distribution

If we're given the point estimate cost PE, α_{PE}, and CV, then the mean and standard deviation of $Cost_{Pgm}$ are given by the following:

$$\mu_{Cost_{Pgm}} = x_{PE} - z_{PE} \frac{Dx_{PE}}{1 + Dz_{PE}} \quad (3)$$

$$\sigma_{Cost_{Pgm}} = \frac{Dx_{PE}}{1 + Dz_{PE}} \quad (4)$$

where D is the coefficient of variation (CV), x_{PE} is the program's point estimate cost, and z_{PE} is the value such that $P(Z \leq z_{PE}) = \alpha_{PE}$ where Z is the standard (or unit) normal random variable. Values for z_{PE} are available in look-up tables for the standard normal, provided in Appendix B [Garvey, 2000].

With the values computed from Equation 3 and Equation 4, the distribution function of $Cost_{Pgm}$ can be fully specified, along with the probability that $Cost_{Pgm}$ may take any particular outcome, such as the protect scenario cost. WSARA confidence levels can be determined.

Note: eSBM also provides the equations needed if a program's cost is best represented by a lognormal distribution

eSBM Equation Example

- For normal distribution

Suppose the distribution function of $Cost_{Pgm}$ is normal. Suppose the program's point estimate cost is \$100M and this was assessed to fall at the 25th percentile. Suppose the type and life cycle phase of the program is such that 30 percent variability in cost around the mean has been historically seen. Suppose the program's protect scenario was defined and determined to cost \$145M.

a) Compute the mean and standard deviation of $Cost_{Pgm}$.
b) Plot the distribution function of $Cost_{Pgm}$.
c) Determine the confidence level of the protect scenario cost and its associated cost reserve.
d) Determine the program cost outcome associated with the WSARA confidence level.

3 Inputs

$$x_{PE} = 100$$
$$\alpha_{PE} = 0.25$$
$$D = CV = 0.30$$

Solution

a) From Equation 3 and Equation 4

$$\mu_{Cost_{Pgm}} = x_{PE} - z_{PE}\frac{Dx_{PE}}{1+Dz_{PE}} = 100 - z_{PE}\frac{(0.30)(100)}{1+(0.30)z_{PE}}$$

$$\sigma_{Cost_{Pgm}} = \frac{Dx_{PE}}{1+Dz_{PE}} = \frac{(0.30)(100)}{1+(0.30)z_{PE}}$$

We need z_{PE} to complete these computations. Since the distribution function of $Cost_{Pgm}$ is normal, it follows that $P(Cost_{Pgm} \le x_{PE}) = \alpha_{PE} = P(Z \le z_{PE})$, where Z is a standard normal random variable. Values for z_{PE} are available in statistical tables. In this case, $P(Z \le z_{PE} = -0.6745) = 0.25$; therefore, with $z_{PE} = -0.6745$ we have

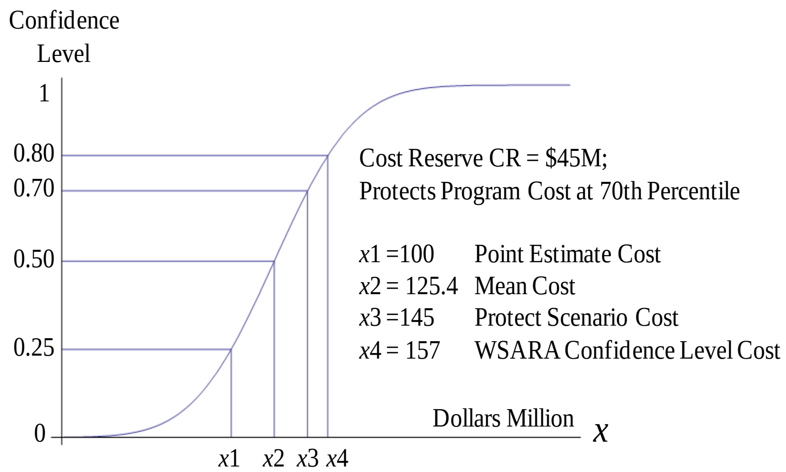
eSBM Equation Example

- For normal distribution

$$\mu_{Cost_{Pgm}} = x_{PE} - z_{PE}\frac{Dx_{PE}}{1+Dz_{PE}} = 100 - z_{PE}\frac{(0.30)(100)}{1+(0.30)z_{PE}} = 125.4 \text{ (\$M)}$$

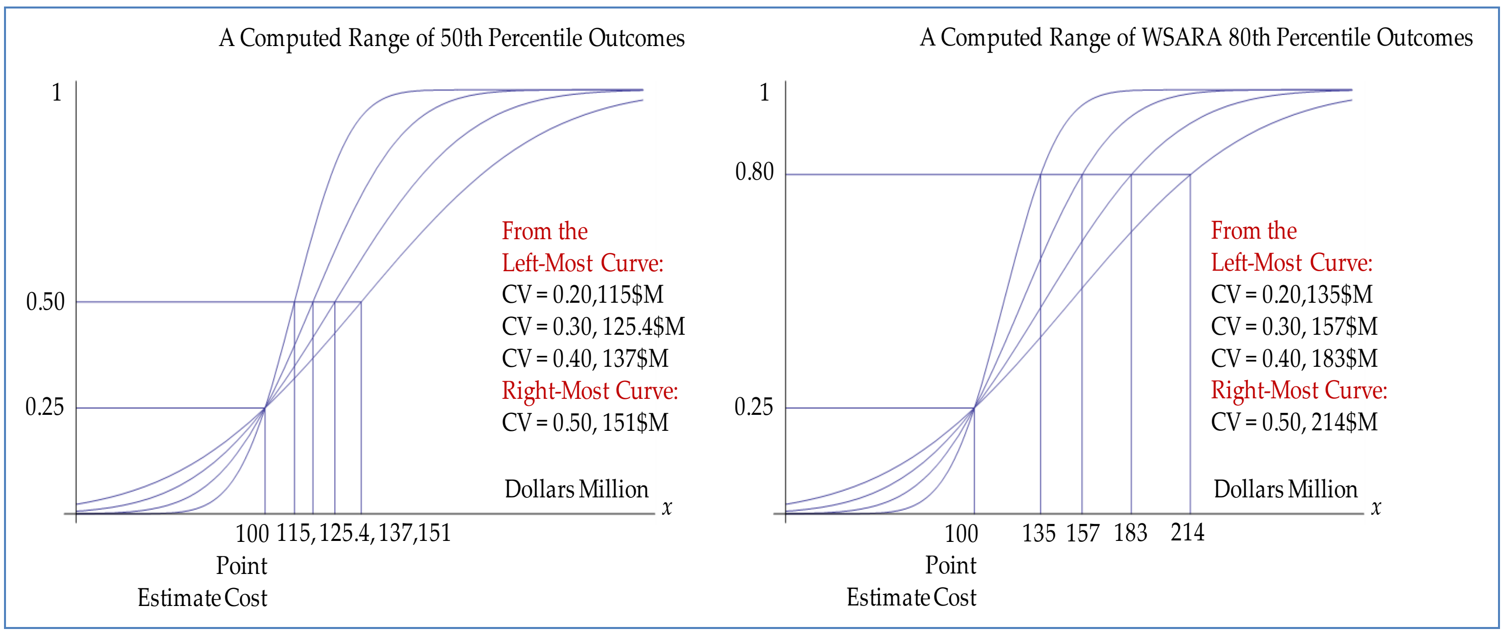
$$\sigma_{Cost_{Pgm}} = \frac{Dx_{PE}}{1+Dz_{PE}} = \frac{(0.30)(100)}{1+(0.30)z_{PE}} = 37.6 \text{ (\$M)}$$

b) A plot of the probability distribution function of $Cost_{Pgm}$ is shown. This is a normal distribution with mean $125.4M and standard deviation $37.6M, as determined from a).



eSBM Sensitivity Analysis

- Guidance for selection of CV
  - Point in life-cycle
  - Uniqueness of program or scenario
- Examples for 50th and 80th percentiles



eSBM Summary

- Realization of problem
  - Cumulative probability distributions of cost, or S-curves, too often understate true, underlying risk and uncertainty
- Remedy
  - In 2006, the Scenario-Based Method (SBM) was introduced
    - Alternative to advanced statistical methods for generating measures of cost risk
    - Intent was a return to “the basics” of what decision-makers need from a cost risk analysis and to find a more straightforward approach than experiences to date
  - enhanced SBM (eSBM) – an historical data-driven application of SBM
    - Integrates historical cost performance data into SBM’s algorithms
    - Provides a context for applying SBM from a WSARA perspective

Conjectures of CV Behavior

Conjectures*

- Estimation Consistency
  - CVs from ICEs jibe with acquisition experience
    - Evaluation of accuracy more problematic
- Decline During Acquisition
  - CVs decrease throughout acquisition lifecycle
    - MS A, B, C, FRP DR
- Platform Homogeneity
  - CVs equivalent for aircraft, ships, and other platform types
    - Cost growth factors and variances

Conjectures

- Adjustment Decline
  - CVs decrease when adjusted for changes in quantity and inflation
- Invariance of Secular Trend
  - CVs steady long-term

*"Development and Application of CV Benchmarks," Flynn; DODCAS 2011

Data Collection

Source

- SAR Summary Sheets
  - Total program acquisition cost
    - R&D, procurement, MILCON
  - Tied to acquisition milestones
    - Planning Estimate (PE) for MS A
    - Development Estimate (DE) for MS B
    - Production Estimate (PdE) for MS C
    - Historically, equivalent to milestones I, II, and III
  - Base-year$ and then-year$
  - From 1985 to 2009

Focus

- DON MDAPS only
- 100 observations
- Baseline Estimates date from 1969 to 2003
  - Mostly completed programs but a few on-going such as LPD-17 and LCS
  - Ships, submarines, missiles, and aircraft predominate
  - Excludes notables such as A-12 and Presidential Helicopter

Cost Growth Calculations

Cost Growth Factors (CGFs)

- Unadjusted for quantity changes
  - Current Estimate in base-year$ divided by Baseline Estimate in base-year$
    - Adjusted for changes in inflation
  - Current Estimate in then-year$ divided by Baseline Estimate in then-year$
    - Completely unadjusted
- Adjusted for quantity changes
  - Also in base-year and then-year$

Quantity Adjustment

- Three choices
  - Adjust baseline estimate to reflect current quantities
    - CGF = CE/(BE + QΔ)
    - Analogous to Paasche Index
    - Used in SARs
  - Adjust current estimate to reflect baseline quantities
    - CGF = (CE – QΔ)/BE
    - Analogous to Laspeyres Index
  - "Fisher" index = square root of the product of the first two
- CV deltas insignificant (.02 and .04 spreads in BY$ & TY$ for ships & submarines)

Cost Growth Calculations

Example: CG-47 Class

- Baseline Estimate (BE) of 1978
  - 16 ships at $9.01B (BY$) and $14.08B (TY$)
- Current Estimate (CE) of 1992
  - 27 ships at $14.11B (BY$) and $23.28B (TY$)
    - Deltas in BY$
      - $5.10B total & $5.49B quantity
    - Deltas in TY$
      - $9.20B total & $11.74B quantity
    - Estimating change negative

Cost Growth Factors

- Unadjusted for quantity Δ
  - Then-year dollars
    - ➢ $23.28B/$14.08B = 1.65
  - Base-year dollars
    - ➢ $14.11B/$9.01B = 1.57
- Adjusted for quantity Δ, using OSD methodology
  - Then-year dollars
    - ➢ $23.28B/($14.08B + $11.74B) = 0.90
  - Base-year dollars
    - ➢ $14,11B /($9.01B + $5.49B) = 0.97

Provenance of Estimates

Analysis of Deltas

SAR BE		Program Office's Acquisition Cost Estimate		ICE (CAIG for ID; NCCA for IC)		Ratio of POACE to SAR BE	Ratio of POACE to SAR BE	Ratio of ICE to SAR BE	Ratio of ICE to SAR BE
in BY$	in TY$	in BY$	in TY$	in BY$	in TY$	in BY$	in TY$	in BY$	in TY$
$2,877	$3,093	$2,817	$3,032	$3,130		0.98	0.98	1.09	
$4,123	$4,310	$4,123		$4,104		1.00		1.00	
$45,633	$71,081	$45,500		$47,400		1.00		1.04	
	$8,636		$8,400		$8,580		0.97		0.99
$26,494	$31,429	$24,490		$26,810		0.92		1.01	
$31,548	$36,296	$32,800		$39,100		1.04		1.24	
$10,627	$11,425	$10,727				1.01			
$43,490	$46,826	$43,000				0.99			
$4,263	$4,890	$4,245		$4,349		1.00		1.02	
$2,977	$3,290	$3,019	$3,284		$3,505	1.01	1.00		1.07
					Means =	0.99	0.98	1.07	1.03
								1.03 without outlier	

Comparisons based on available data for cost estimates of recent vintage (1990 and later)

- 6 ACAT ID programs (OSD CAIG ICE)
- 4 ACAT IC programs (NCCA ICE)

Sample Data at MS B

n = 50

Database Elements

- Base year, baseline type, platform type
- Baseline Estimate
  - Base Year$
  - Then Year$
  - Quantity
- Changes to Date
  - Base Year$
  - Then Year$
  - Quantity
- Current Estimate
  - Base Year$
  - Then Year$
  - Quantity
- Quantity Changes
  - Base Year$
  - Then Year $
- Date of last SAR

F/A-18 E/F
JSOW
Expeditionary Fighting Vehicle (formerly AAAV)
MIDS - Low Volumne Terminal (LVT)
Cooperative Engagemer
H-1 UPGRADES
MH-60S
TACTICAL TOMAHAWK
MH-60R
E-2D Advanced Hawkeye
EA-18G (Electronic Attac
COBRA JUDY REPLACEMI
P-8A
Mobile User Objective S
SM-6
AGM-88E AARGM

F-14D
F/A-18 C/D
Fixed Distributed System (FDS)
HARM
HARPOON
LAMPS MK III
MK-48 ADCAP
MK-50 TORPEDO
PHOENIX AIM-54C
SEA LANCE (ASW-SOW)
SH-60F
SPARROW (AIM-7M)
STANDARD MISSILE-2 (Blc
TOMAHAWK Baseline Imp
V-22
AN/BSY-2
SLAT (Supersonic Low Alt

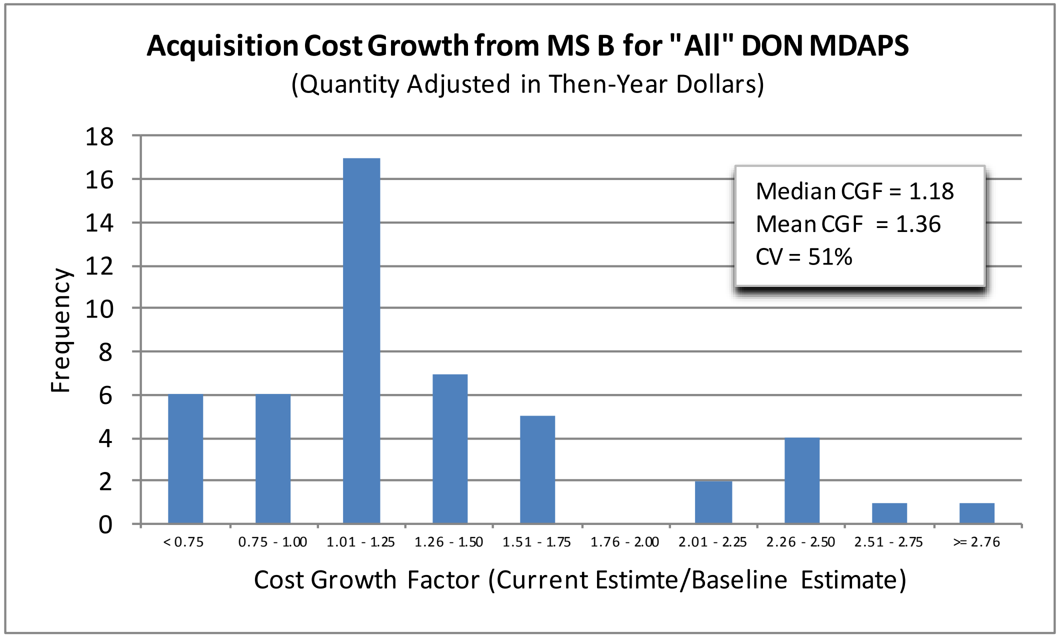
DDG-51 Destroyers (Arleigh Burke Class)
DDG-1000 Destroyers (Zumwalt Class)
CVN-78 Aircraft Carriers (Gerald R. Ford Class)
LPD-17 Amphibious Transport Dock (San Antonio Class)
LHA-6 Amphibious Assault Ships (America Class)
SSN-774 Attack Submarines (Virginia Class)
LHD-1
CG-47
SSN-688 Submarines
Strategic Sealift
FFG-7
AN/BSY-1 (Submarine Advanced Combat System; SUBACS)
Airborne Self Protection Jammer (ASPJ)
AV-8B
C/MH-53E
E-6A
F-14A

MS B: All Programs

All DON MDAPs at MS B

- Distribution skewed to right
- Adjustments for changes in quantity and inflation decrease values of CGFs and CVs
- CVs sensitive to outliers
  - E.g., removing Harpoon decreases quantity-adjusted TY$ CV to 0.45
    - 2nd oldest datum (1970 baseline)

Cost Growth Factors & CVs for All DON MDAPs at MS B for 1969 & Later; n = 50				
	(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.48	1.84	1.23	1.36
Standard Deviation	0.94	1.60	0.44	0.69
CV	0.63	0.87	0.36	0.51

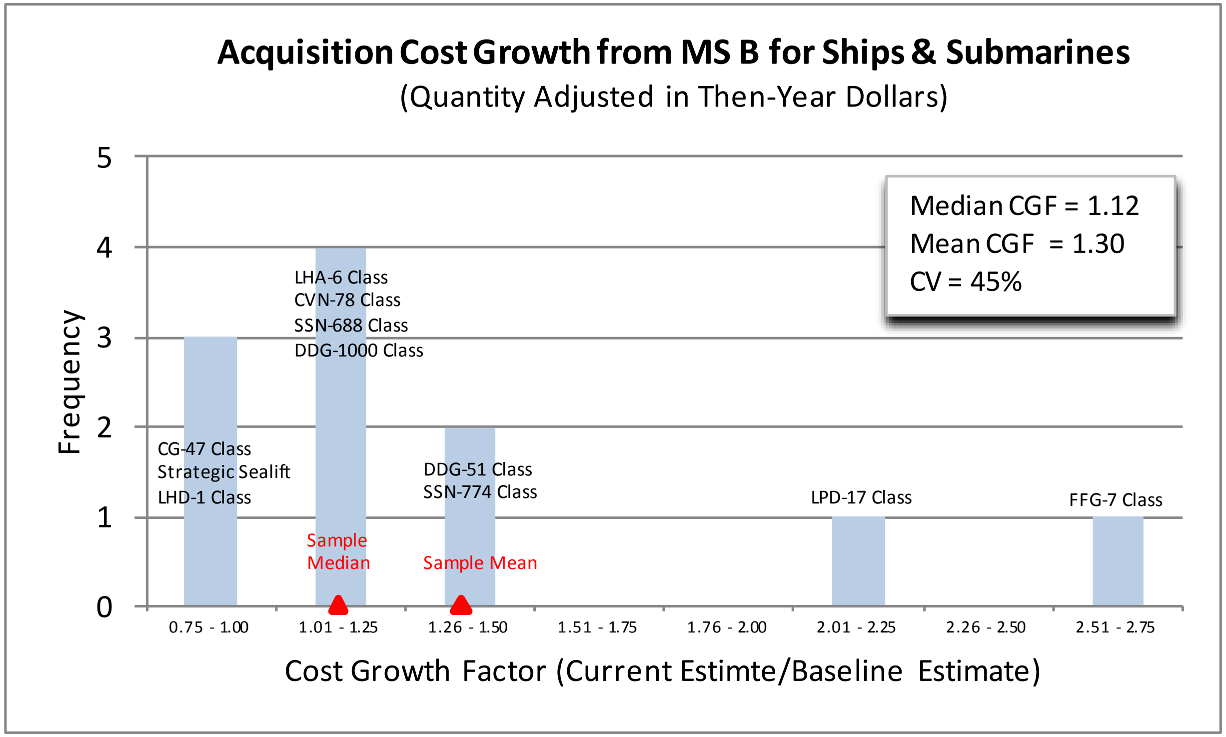


MS B: Ships & Submarines

Comparison with "All DON"

- Median CGF = (1.18, 1.12)
- Mean CGF = (1.36, 1.30)
- CV = (51%, 45%)

Cost Growth Factors & CVs for Ship & Sub MDAPs at MS B; n = 11				
	(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.78	2.17	1.21	1.30
Standard Deviation	0.95	1.38	0.30	0.58
CV	0.54	0.64	0.25	0.45

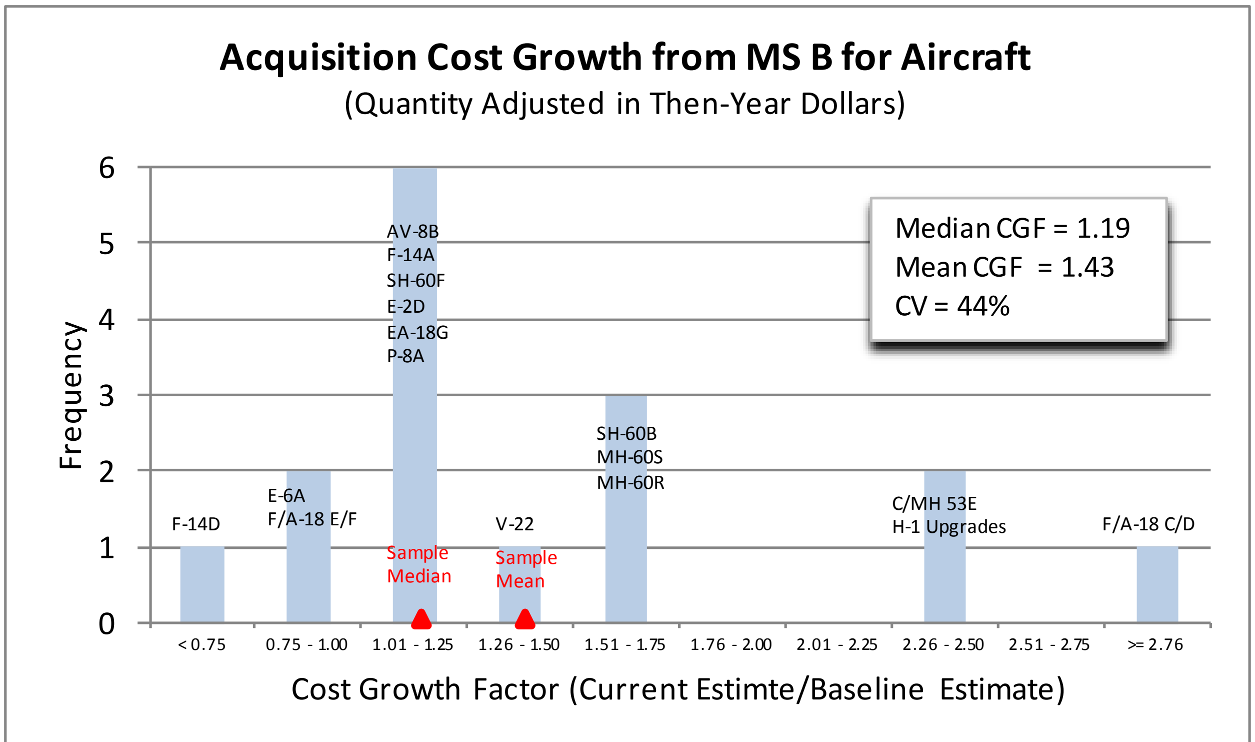


MS B: Aircraft

Comparison with All DON, Ships

- Median CGF = (1.18, 1.12, 1.19)
- Mean CGF = (1.36, 1.30, 1.43)
- CV = (51%, 45%, 44%)

Cost Growth Factors & CVs for Aircraft MDAPs at MS B; n = 16					
Statistics		(Without Qty Adjustment)		(Quantity Adjusted)	
		Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean		1.55	2.03	1.29	1.43
Standard Deviation		0.89	1.87	0.43	0.63
CV		0.57	0.92	0.34	0.44

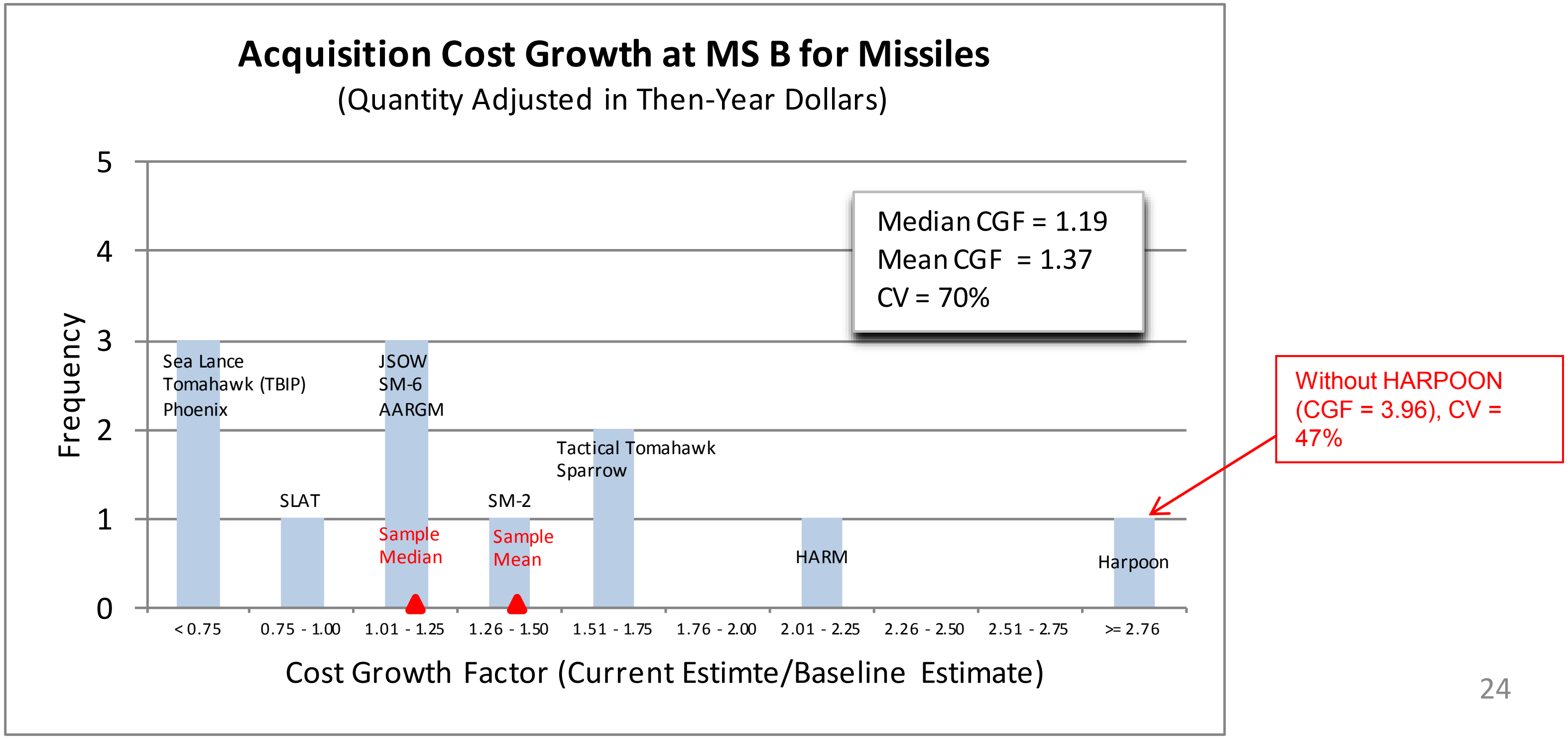


MS B: Missiles

Comparison with All DON, Ships, Aircraft

- Median CGF = (1.18, 1.12, 1.19, 1.19)
- Mean CGF = (1.36, 1.30, 1.43, 1.37)
- CV = (51%, 45%, 44%, 70%)

Cost Growth Factors & CVs for Missile MDAPs at MS B; n = 12				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.44	1.94	1.19	1.37
Standard Deviation	1.19	1.93	0.49	0.96
CV	0.82	0.99	0.41	0.70

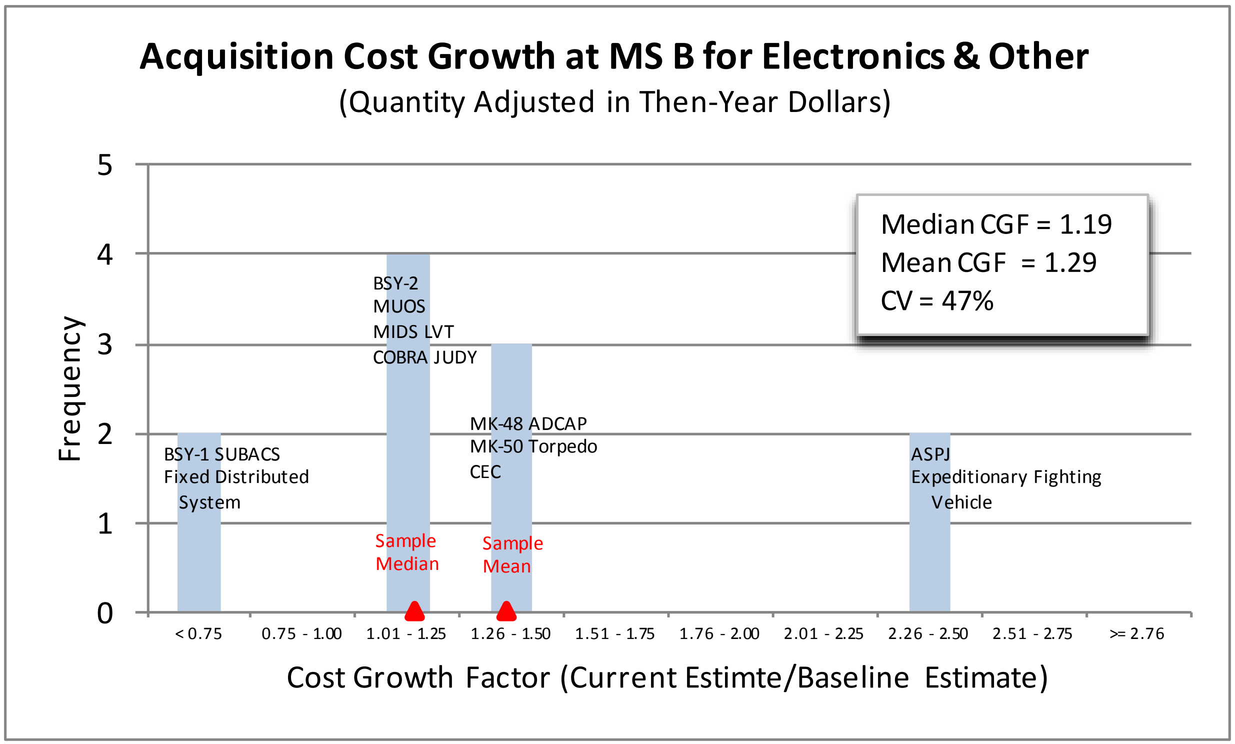


MS B: Electronics & Other

Comparison with All DON, Ships, Aircraft, Missiles

- Median CGF = (1.18, 1.12, 1.19, 1.19, 1.19)
- Mean CGF = (1.36, 1.30, 1.43, 1.37, 1.29)
- CV = (51%, 45%, 44%, 70%, 47%)

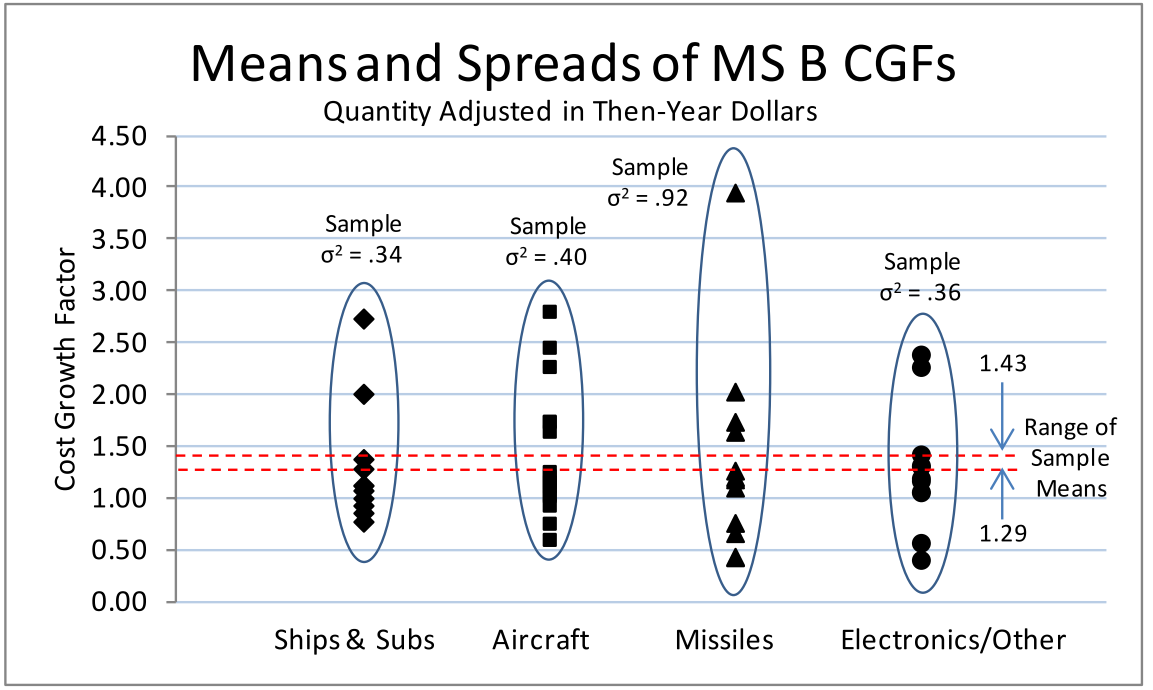
Cost Growth Factors & CVs for Electronics & Other MDAPs at MS B; n = 11				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.14	1.14	1.22	1.29
Standard Deviation	0.67	0.69	0.55	0.60
CV	0.59	0.61	0.45	0.47



Hypothesis Testing for MS B

Hypothesis

- Homogeneity of CGF means
  - H_o: $\mu_1 = \mu_2 = \ldots = \mu_k$, where μ_i is a platform population mean CGF
  - H_a: $\mu_i \neq \mu_j$, for at least one (i,j) pair
  - $F_{(3,45)} = 0.12$ (from ANOVA)
    - ➢ Implies that variation in platform-level sample means is not, at the 5% level of significance, statistically distinguishable from noise



Hypothesis Testing for MS B

Hypothesis

- Homogeneity of CGF variances
  - H_o: $\sigma^2_1 = \sigma^2_2 = \ldots = \sigma^2_k$, where σ^2_i is a platform population variance CGF
  - H_a: $\sigma^2_i \neq \sigma^2_j$, for at least one (i,j) pair
  - Statistical tests:
    - Pairwise comparisons
    - Levene test for *k* samples

Sample Pairwise F Statistics				
Platforms	Ships & Subs	Aircraft	Missiles	Elex & Other
Ships and Subs		2.840	2.940	2.970
Aircraft			2.510	2.720
Missiles				2.940
Elex and Other				

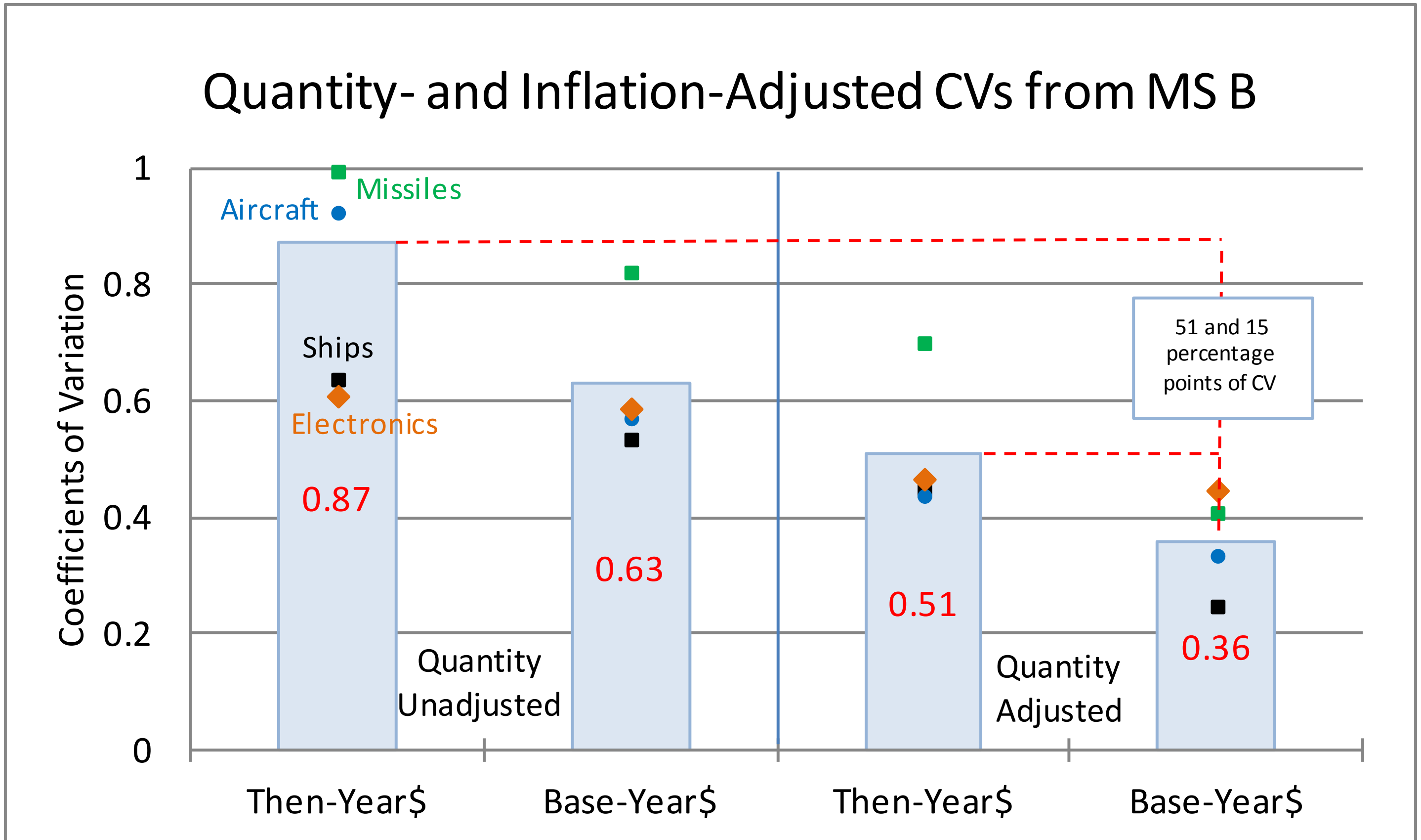
Test Results

- Pairwise comparisons
  - In all cases, H_o is not rejected at 5% level of significance
- Levene's test
  - For skewed distributions
  - $F_{(3,47)} = 0.46$ versus critical value of 4.23; H_o not rejected
- In both cases, platform-level sample variances not statistically distinguishable from noise

Homogeneous means and variances strongly support the conjecture of homogeneous CVs

Other Findings for MS B

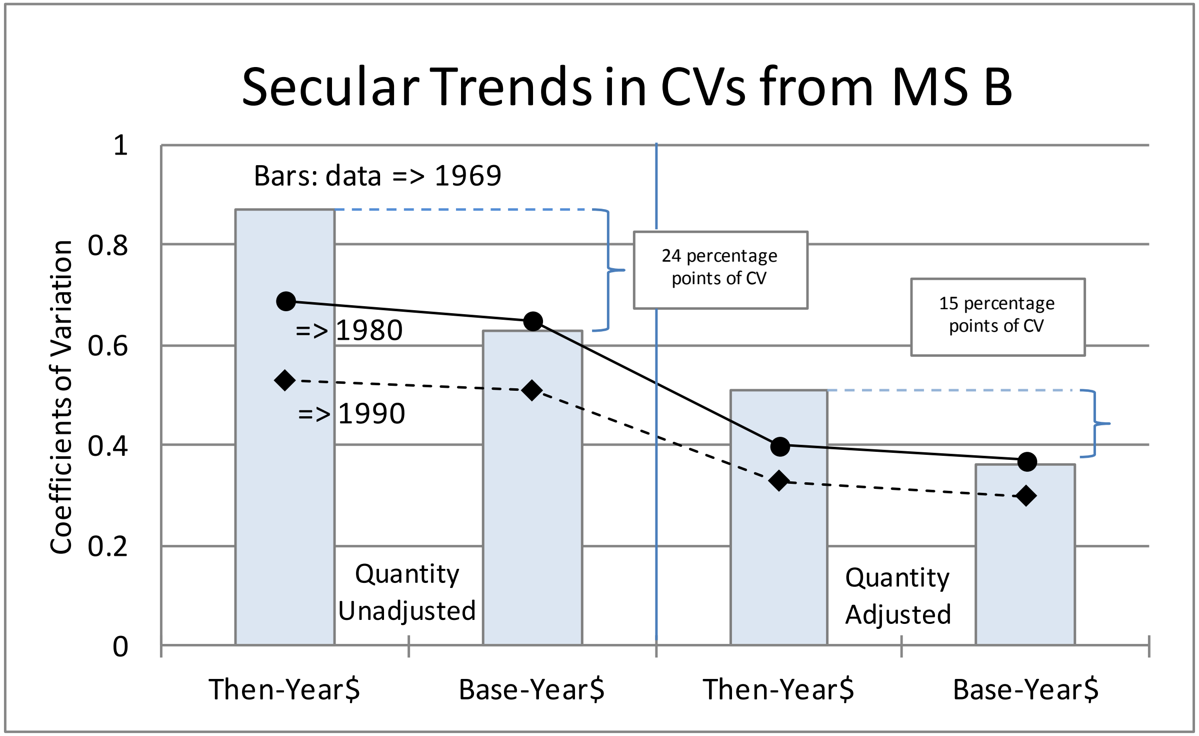
- CVs decline monotonically with adjustments
  - 15 percentage points for inflation, after quantity adjustment
    - Perhaps due to volatility of average annual rates during the Nixon/Ford (6.5%), Carter (10.7%), Reagan (4.0%), G.H.W. Bush (3.9%), and Clinton (2.7%) administrations



Other Findings for MS B

Secular decline in CVs

- Especially in TY$
  - Less drop in BY$
- Inflation stability
  - After the turmoil of the late 1970s
    - Less variance and greater accuracy in OMB rates
    - Less CV (TY$ to BY$)
  - Unclear if trend will continue in long run
- Caution:
  - Confidence lessens as sample size decreases



Sample Data at MS C

n = 43

All DON MDAPs at MS C

- PdE represents estimated total program acquisition cost
  - Includes sunk R&D and MILCON costs
- Roughly 20% had a DE, too

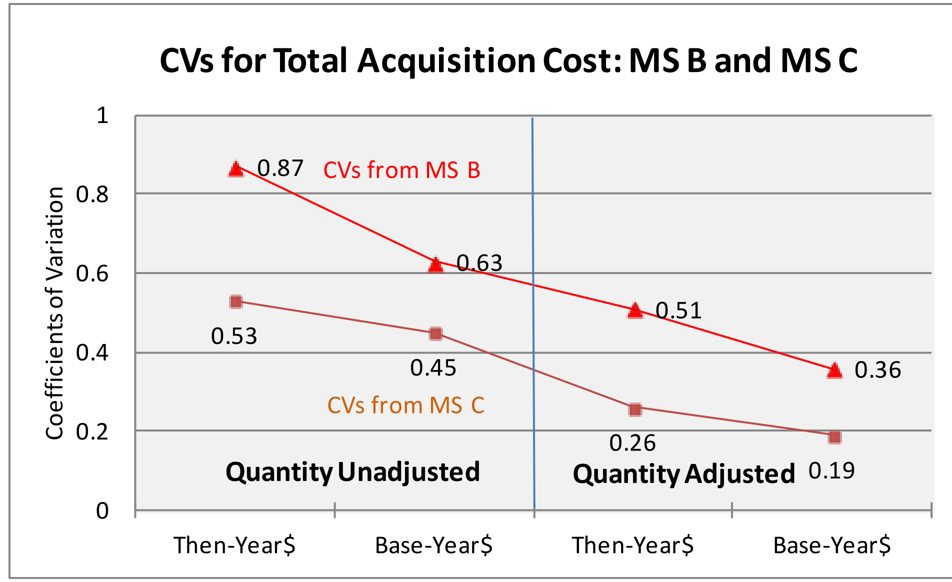
DDG-51 Destroyers (Arleigh Burke Class)
CVN-77 (1 ship) from CVN-68 Aircraft Carriers (Nimitz Class)
T-AKE Dry Cargo/Ammunition Ships (Lewis and Clark Class)
AOE-6
CVN-72/73
CVN-74/75
Landing Craft Air Cushi
LSD-41 Landing Ship Do
LSD-49 Landing Ship Do
MCM-1 Mine Counterm
TAO-187 Fleet Oiler
Trident II Submarines
CVN-76
MHC-51 Mine Hunter C
T-AGOS
CVN-68 Class (two ship
CVN-68 Class (one ship
Battleship Reactivatior
SSN-21 & AN/BSY-2
A-6E/F
AN/SQQ-89 Anti-Subm
E-2C

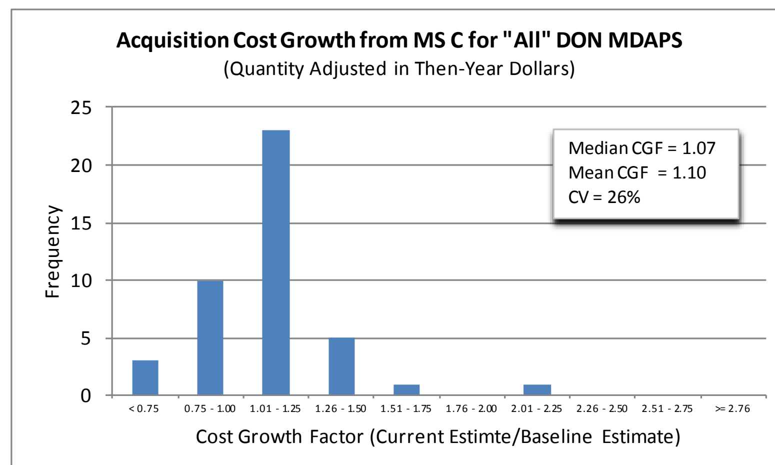
EA-6B
F-14D
MK-48 ADCAP
P-3C
PHALANX CIWS
T-45TS
TRIDENT II MISSILE
V-22
UHF FOLLOW-ON
ROTHR (Relocatable Over the Horizon Radar)
F/A-18 E/F
JSOW Baseline/Unitary-108
MIDS - Low Volume Terminal (LVT)
Navy EHF Satellite Communications Program (NESP)
AV-8B REMANUFACTURE
Cooperative Engagement Capability (CEC)
E-2C REPRODUCTION
MH-60S
TACTICAL TOMAHAWK
MH-60R
EA-18G (Electronic Attack - 18G Growler)

MS C: All Programs

All DON MDAPs at MS C

- CVs uniformly lower
- Cost growth factors less compared to DE values
  - Mean (1.10 versus 1.36)
  - Median (1.07 versus 1.18)
  - Similar trend for the 9 programs with both DEs and PdEs
- Distribution less skewed





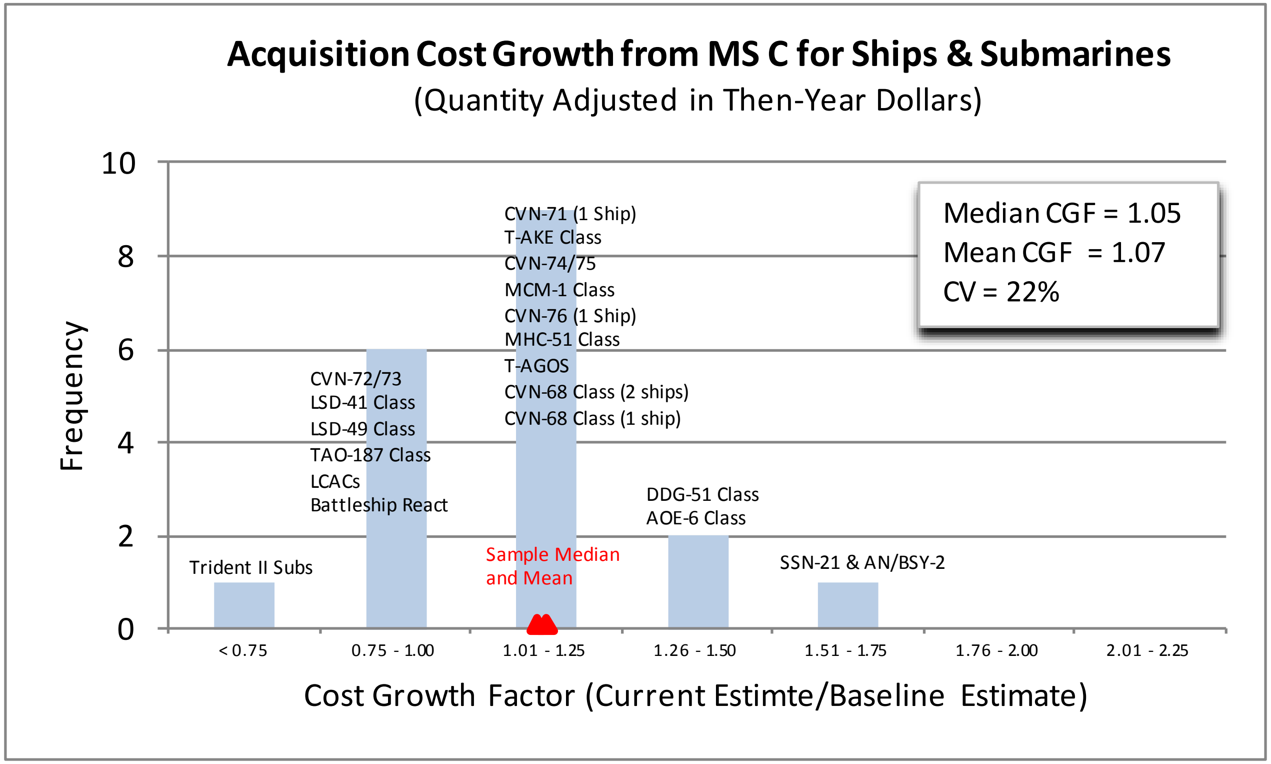
Cost Growth Factors & CVs for All DON MDAPs at MS C for 1969 & Later; n = 43				
	(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.11	1.08	1.11	1.10
Standard Deviation	0.50	0.58	0.21	0.28
CV	0.45	0.53	0.19	0.26

MS C: Ships & Submarines

Comparison with "All DON"

- Median CGF = (1.07, 1.05)
- Mean CGF = (1.10, 1.07)
- CV = (26%, 22%)

Cost Growth Factors & CVs for Ship & Sub MDAPs at MS C; n = 19				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.15	1.12	1.11	1.07
Standard Deviation	0.59	0.74	0.15	0.24
CV	0.52	0.66	0.14	0.22



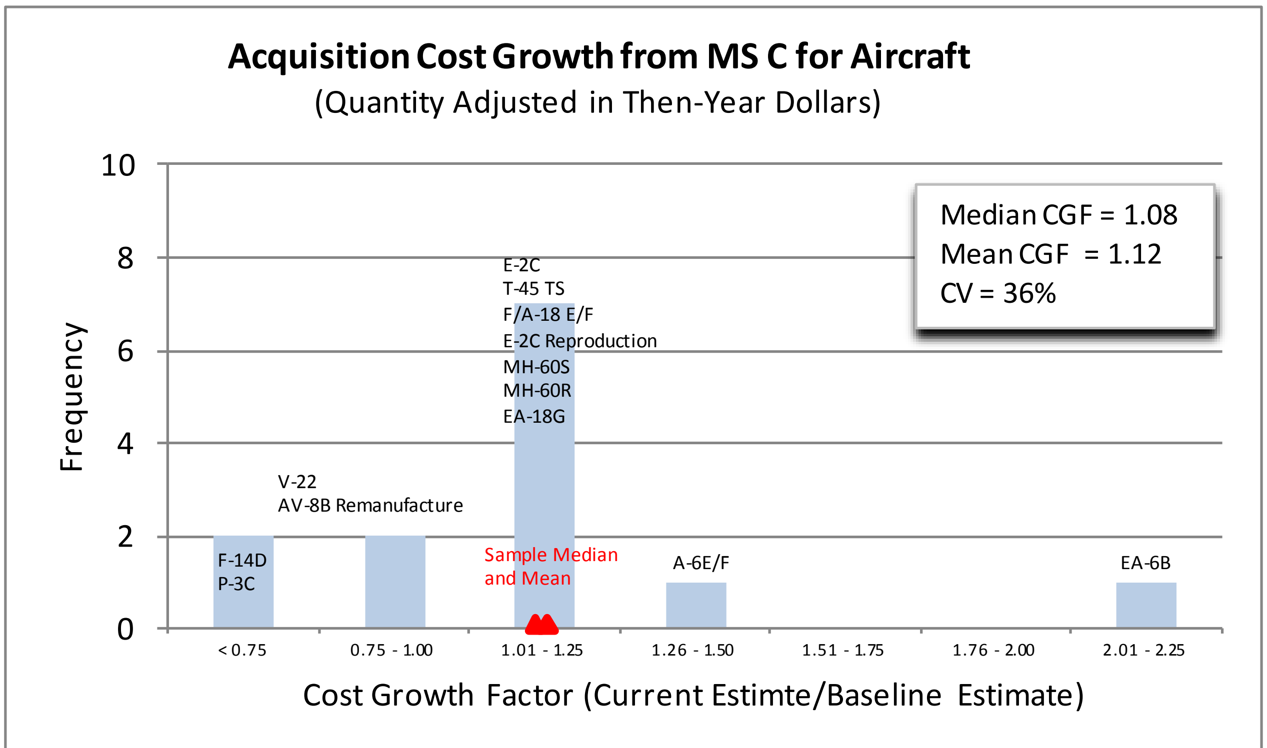
MS C: Aircraft

Comparison with All DON, Ships

- Median CGF = (1.07, 1.05, 1.08)
- Mean CGF = (1.10, 1.07, 1.12)
- CV = (26%, 22%, 36%)

CV falls to 22% without EA-6B outlier

Cost Growth Factors & CVs for Aircraft MDAPs at MS C; n = 13				
Statistics	(Without Qty Adjustment)		(Quantity Adjusted)	
	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	1.17	1.08	1.15	1.12
Standard Deviation	0.44	0.39	0.31	0.40
CV	0.38	0.36	0.27	0.36



MS C: “Other”

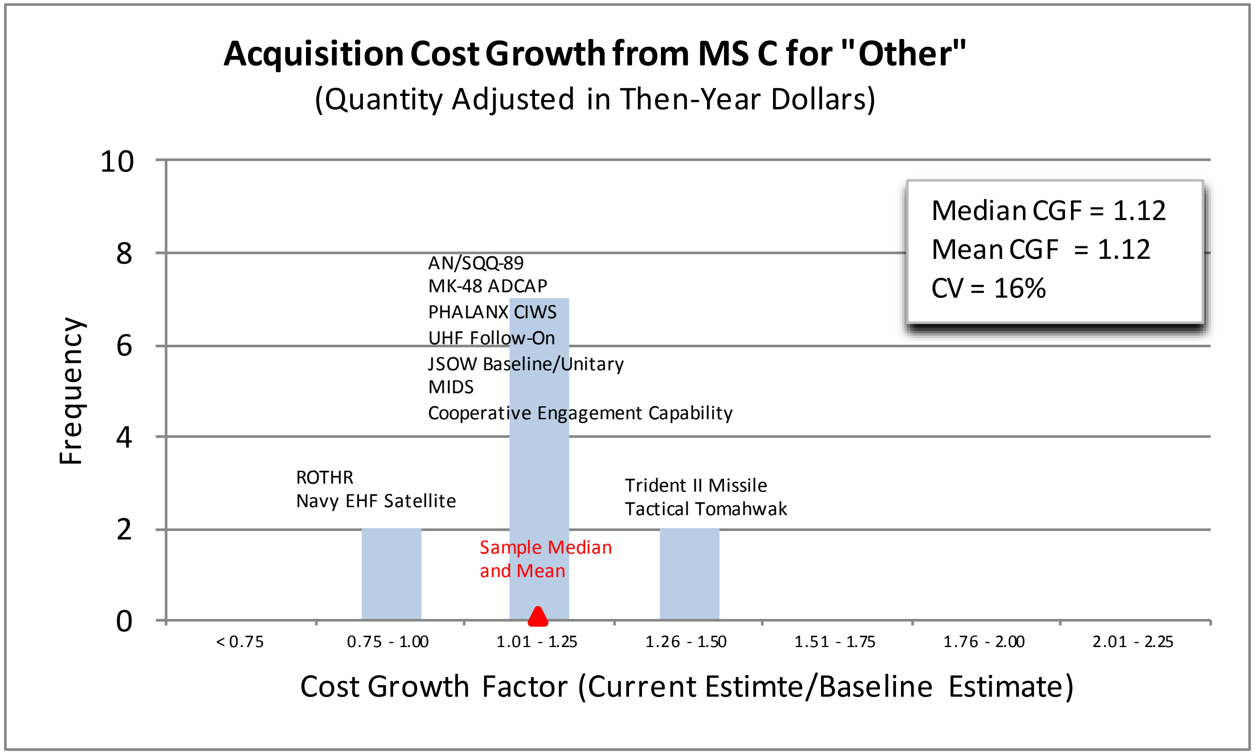
Insufficient sample sizes for missiles and electronics

Comparison with All DON, Ships, Aircraft

- Median CGF = (1.07, 1.05, 1.08, 1.12)
- Mean CGF = (1.10, 1.07, 1.12, 1.12)
- CV = (26%, 22%, 36%, 16%)

CV falls to 22% without EA-6B outlier

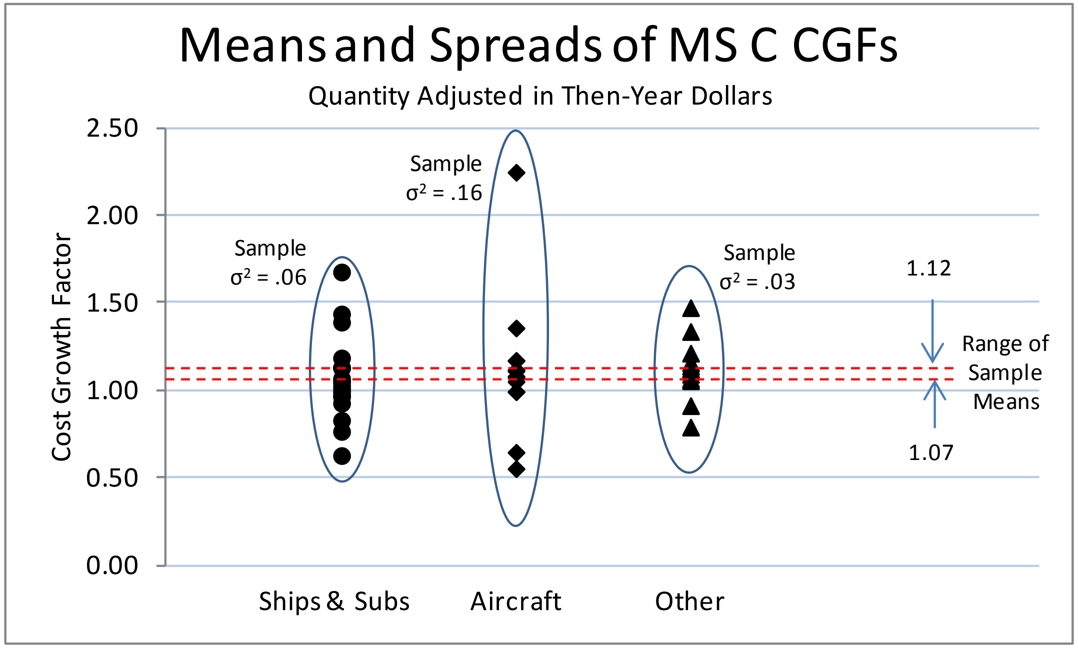
Cost Growth Factors & CVs for "Other" MDAPs at MS C; n = 11				
	(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics	Base-Year$	Then-Year$	Base-Year$	Then-Year$
Mean	0.99	1.00	1.07	1.12
Standard Deviation	0.39	0.45	0.16	0.18
CV	0.40	0.45	0.15	0.16



Hypothesis Testing for MS C

Hypothesis

- Homogeneity of CGF means
  - H_o: $\mu_1 = \mu_2 = \ldots = \mu_k$, where μ_i is a platform population mean CGF
  - H_a: $\mu_i \neq \mu_j$, for at least one (i,j) pair
  - $F_{(2,40)} = 0.16$ (from ANOVA)
    - ➢ Implies that variation in platform-level sample means is not, at the 5% level of significance, statistically distinguishable from noise



Hypothesis Testing for MS C

Hypothesis

- Homogeneity of CGF variances
  - $H_o: \sigma^2_1 = \sigma^2_2 = \ldots = \sigma^2_k$, where σ^2_i is a platform population variance CGF
  - $H_a: \sigma^2_i \neq \sigma^2_j$, for at least one (i,j) pair
  - Statistical tests:
    - Pairwise comparisons
    - Levene test for *k* samples

Sample Pairwise F Statistics			
Platforms	Ships & Subs	Aircraft	Other
Ships and Subs		2.792	1.677
Aircraft			4.682
Other			

Test Results

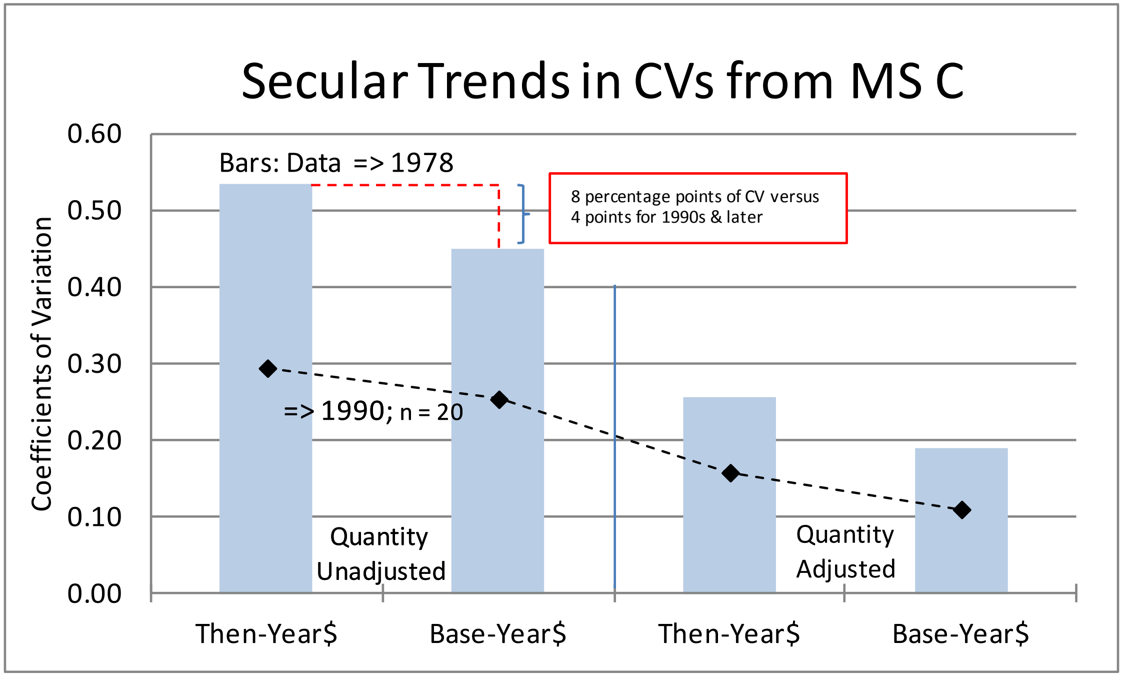
- Mixed
  - Pairwise comparisons
    - H_o rejected for aircraft/ships and aircraft/other
      - Due solely to EA-6B outlier
  - Levene's test
    - For skewed distributions
    - $F_{(2,38)} = 0.54$ versus critical value of 3.25; H_o not rejected
  - On balance, deltas in sample variances not distinguishable from noise

Homogeneous means and some evidence of homogeneous variances support the conjecture of homogeneous CVs

Other Findings for MS C

Secular decline in CVs

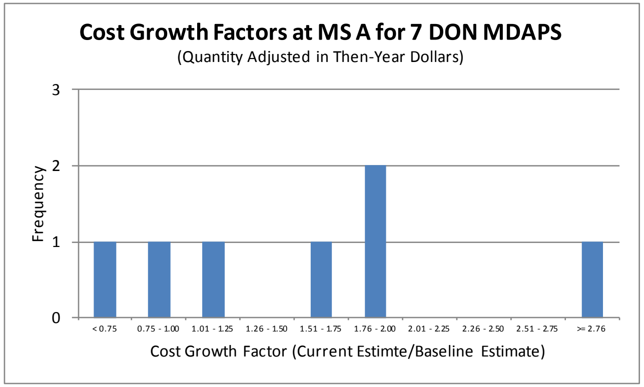
- In both TY$ and BY$
  - Compared to MS B results:
    - Fewer older programs
    - Less inflation impact
- Hypotheses
  - Better estimating
  - Increased program stability
  - Stronger link to ICEs
- Caution: confidence lessens as sample size decreases

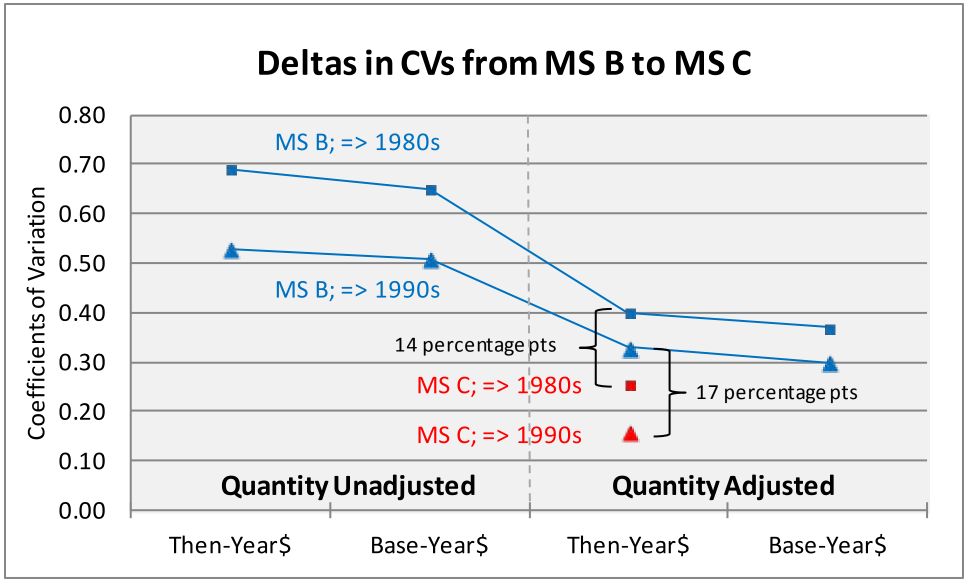


Other Findings: MS A

CVs at MS A

- Insufficient sample size for sound inferences
  - CV of 49% (TYS; quantity-adjusted)
  - Median CGF of 1.65
- Alternative
  - Use MS B-to-C delta as analogy to MS A-to-B delta
    - Assumes equal degree of cost uncertainty and risk between milestones
  - For equal sample time periods, delta ~ 15 percentage points in CV





Summary of Findings

Conjectures

- Estimation Consistency
  - CVs from ICEs jibe with acquisition experience
    - Ad hoc observation suggests underestimation of CVs, at times, in the international defense community
- Decline During Acquisition
  - CVs decrease throughout acquisition lifecycle
    - Strongly supported (MS B to MS C)
- Platform Homogeneity
  - CVs equivalent for aircraft, ships, and other platform types
    - Strongly supported, especially for MS B

Conjectures

- Adjustment Decline
  - CVs decrease when adjusted for changes in quantity and inflation
    - Strongly supported
- Invariance of Secular Trend
  - CVs steady long-term
    - Rejected
    - Evidence of secular decline
    - However, small sample sizes lessen confidence

Policy Considerations

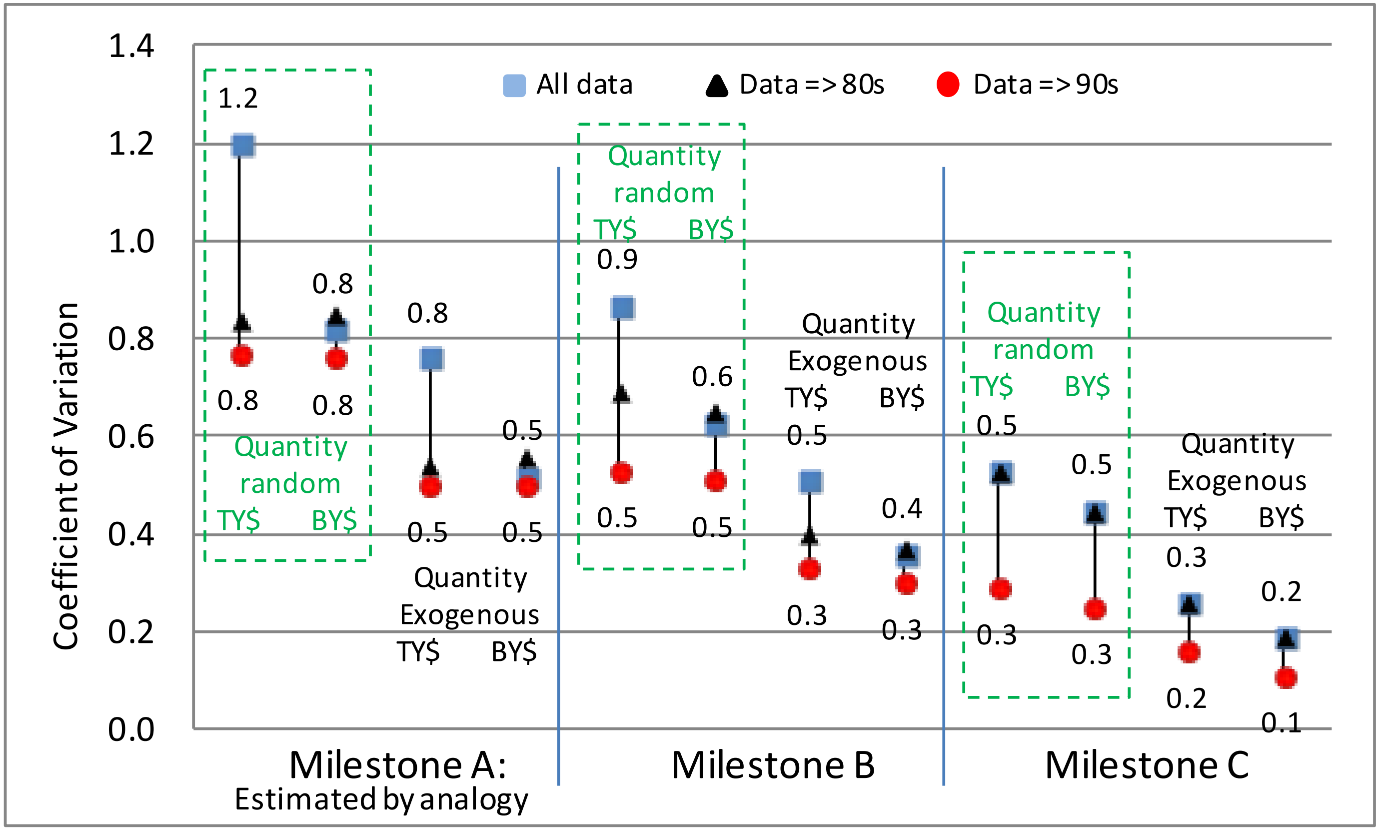
General

- Type of CV to employ
  - Perhaps quantity adjusted in TY$ is best
    - Many programs using non-OSD inflation rates
    - Quantity deltas influenced by JCIDS and Congress
- Possibility of structural change
  - For example,
    - WSARA; systems engineering early on; competitive prototyping; affordability as a KPP; should-cost studies; budgeting to SCPs; capability/cost tradeoffs
  - Uncertain effect on CGFs & CVs

Benchmark CVs

- View of long-term inflation
  - Instability would argue for inclusion of data from 1970s
  - Stability would argue against

Operational Construct



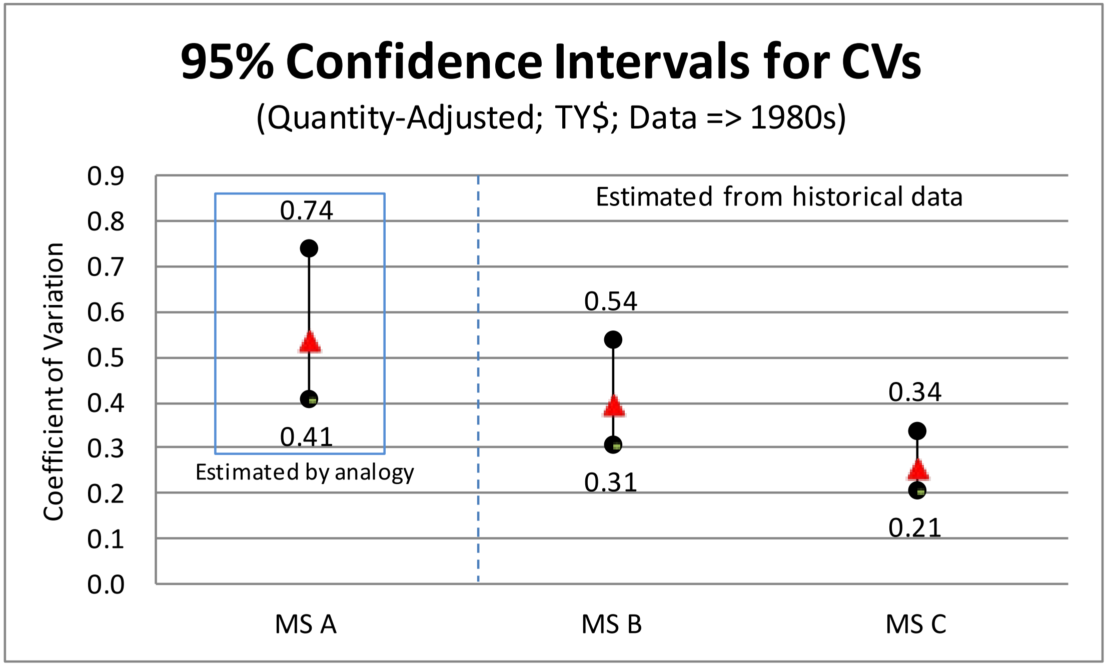
Options for “trigger values” requiring an explanation

- Use historical range
- Use fixed percentage from endpoints
- Use confidence intervals

Operational Construct

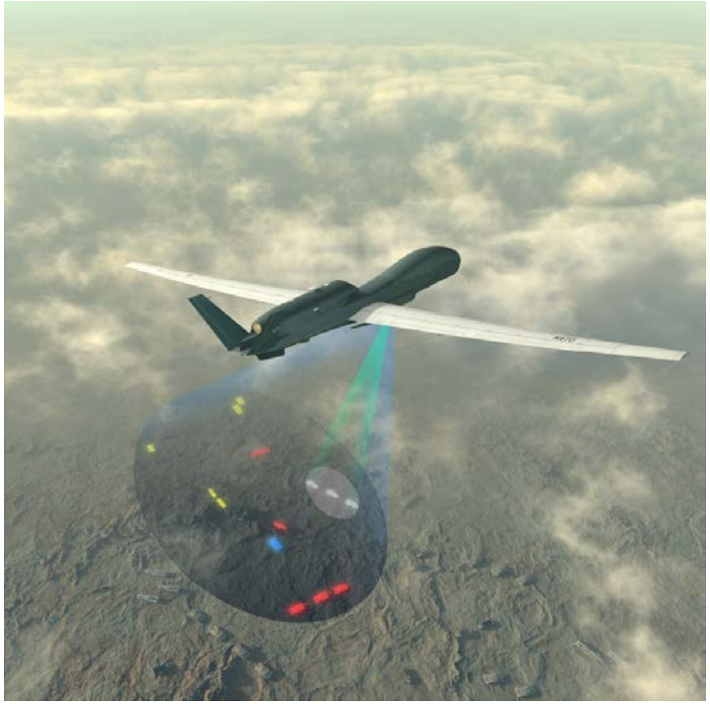
Confidence Intervals

- Assumptions
  - Lognormal distribution at MS B
  - Normal distribution at MS C
- Data from 1980s and later
  - Other confidence intervals available
    - E.g., MS B, using all sample data
    - 0.42, 0.51, 0.66 for lower bound, mean, and upper bound

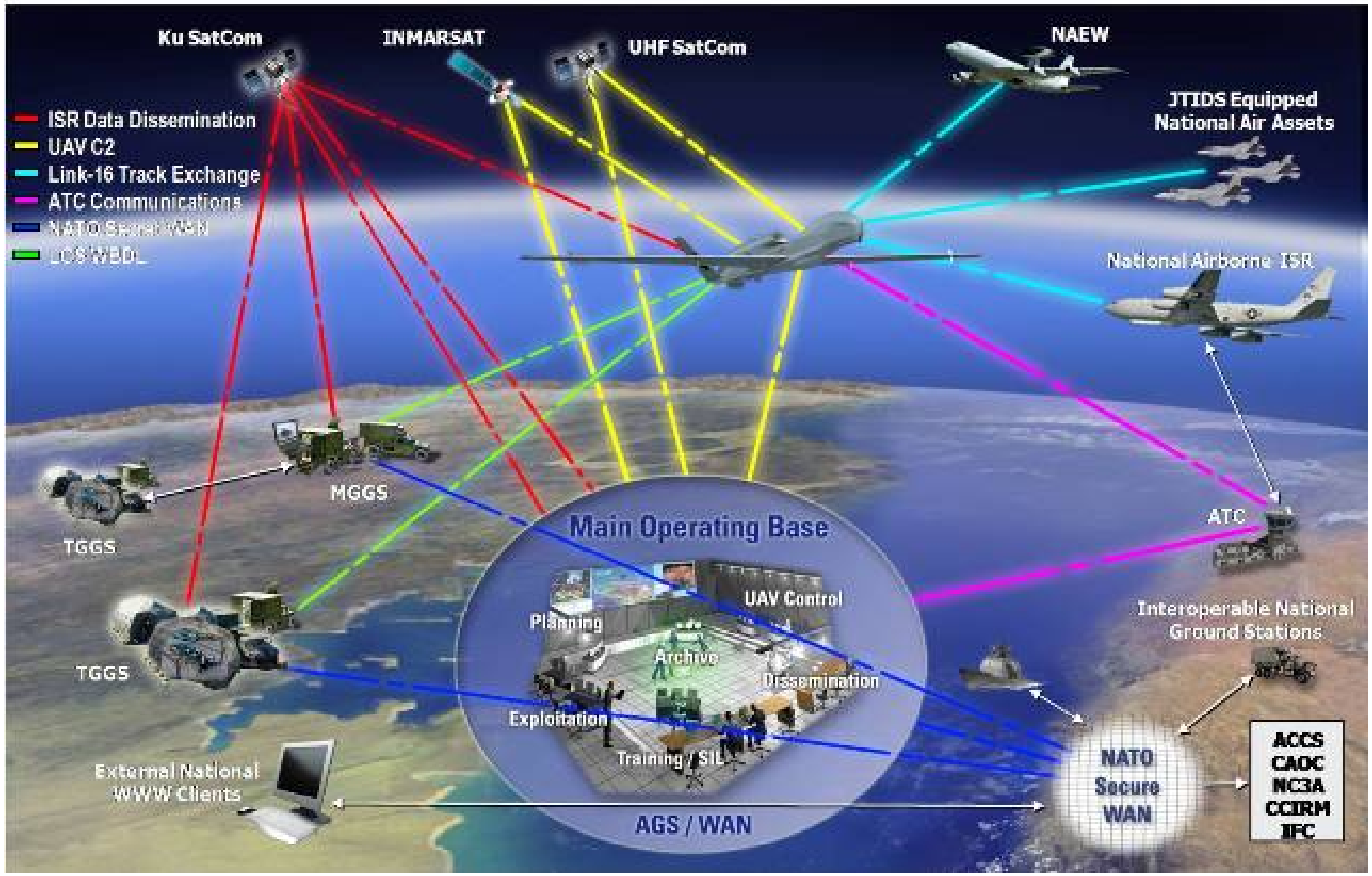


Case Study #1

NATO Alliance Ground Surveillance System



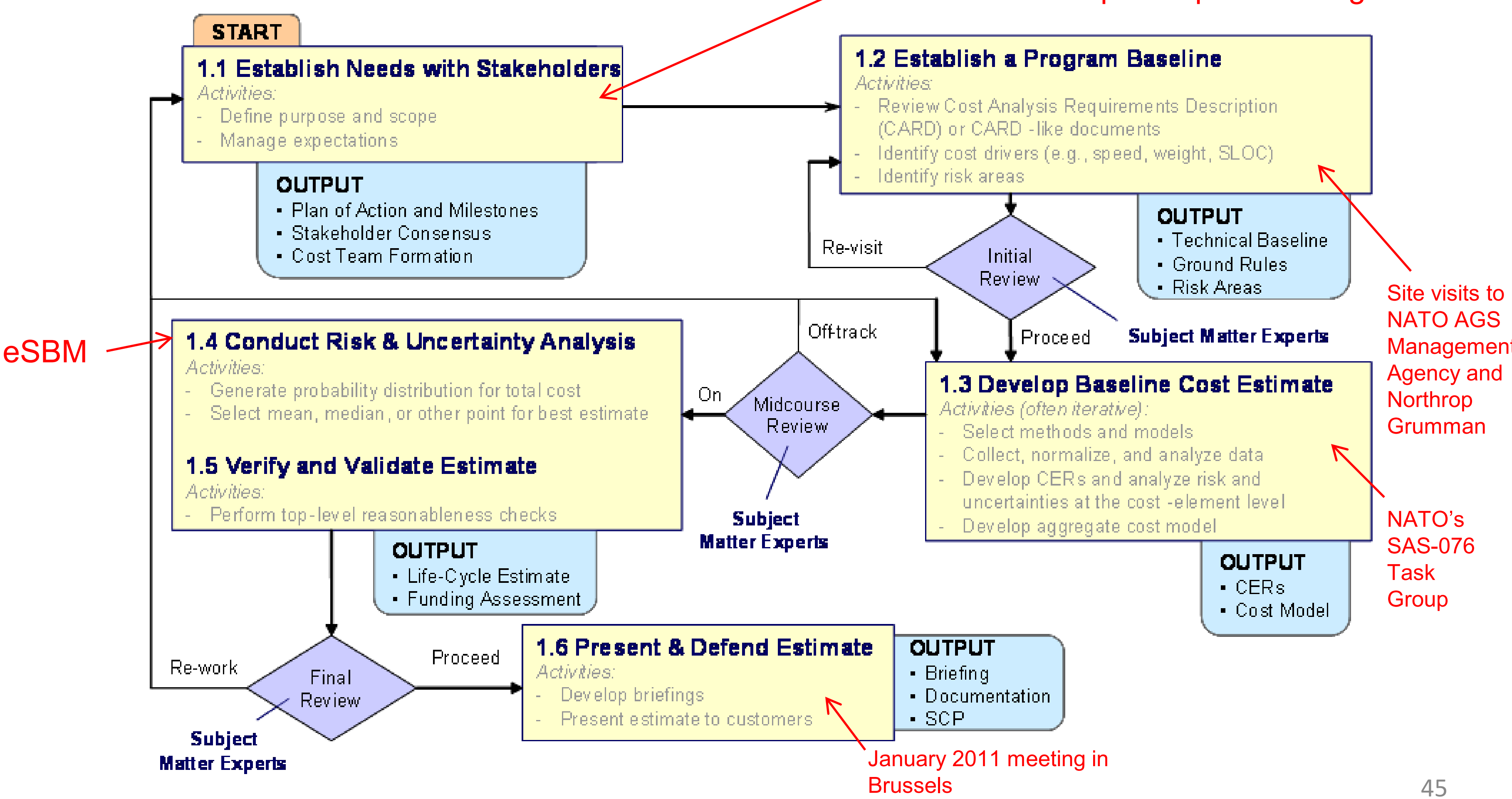
NATO AGS Program



ICE Methodology

Based on DON Cost Estimating Guide

Buy-in from NATO, OSD(CAPE), USD(AT&L), AGS Board of Directors, and “Program Office”; formal ICE development plan *with* signatures



Cost Element Structure

Numeric Element	Cost Element
1.0	**NATO AGS UAV System**
1.1	**Air Vehicle**
1.1.1	Airframe
1.1.1.1	Wing
1.1.1.2	Fuselage
1.1.1.3	Empennage
1.1.1.4	Subsystems
1.1.1.4.1	Nacelle
1.1.1.4.2	Fairings
1.1.1.4.3	Landing Gear + "Other"
1.1.2	Propulsion
1.1.3	Communications
1.1.3.1	DataLinks
1.1.3.2	Satellite Communications
1.1.3.2.1	KU Satellite Radio
1.1.3.2.2	Satellite Communications (SATCOM) Voice
1.1.3.2.3	International Maritime SATCOM
1.1.3.3	UHF/VHF Communications
1.1.3.3.1	UHF/VHF Radios
1.1.3.3.2	UHF Demand Assigned Multiple Access SATCOM
1.1.4	Navigation / Guidance
1.1.4.1	(2) Global Positioning Systems
1.1.4.2	OmniStar Differential Global Positioning System (DGPS)
1.1.4.3	IFF Transponder/ Traffic Alert & Collision (TCAS-II)
1.1.4.4	Worldwide Operations Hardware Suite
1.1.5	Central Computer
1.1.6	Auxiliary Equipment
1.1.7	Integration, Assembly, Test & Checkout
1.2	**Payloads**
1.2.1	Reconnaissance
1.2.1.3	MP-RTIP
1.2.2	NATO AGS Unique
1.2.2.1	Electronic Support Measures (ESM)
1.2.2.2	Radar Warning Receiver (RWR)
1.2.2.3	IFF Interogator

Numeric Element	Cost Element
1.3	**Ground/Support Segment**
1.3.1	Hardware
1.3.1.1	Command and Control (C2) Unit
1.3.1.2	Mobile General Ground Stations
1.3.1.3	Mobile General Communications Stations
1.3.1.4	Transportable General Ground Stations
1.3.1.5	Remote Workstations
1.3.1.6	UAV Flight Trainers
1.3.1.7	Deployable Ground Station Trainers
1.3.2	Software Development
1.3.2.1	Air Vehicle/Payload
1.3.2.2	Mission Operations Support
1.3.2.3	Transportable General Ground Stations
1.3.2.4	Mobile General Ground Stations
1.3.2.5	Mobile General Communications Stations
1.3.2.6	CSOP
1.3.2.7	UAV Command and Control
1.3.2.8	System Integration and Testing
1.4	**Systems Engineering / Program Management**
1.4.1	Systems Engineering (SE)
1.4.2	Program Management (PM)
1.5	**Systems Test & Evaluation**
1.6	**Training**
1.7	**Data**
1.8	**Peculiar Support Equipment**
1.9	**Common Support Equipment**
1.10	**Operational / Site Activation**
1.11	**Industrial Facilities**
1.12	**Initial Spares and Repair Parts**
Add-on	**General and Administrative**
	Facilities Capital Cost of Money
	Profit

Note: To some degree, notional; changed with requirements

ICE Methodology

Unadjusted Point Estimate

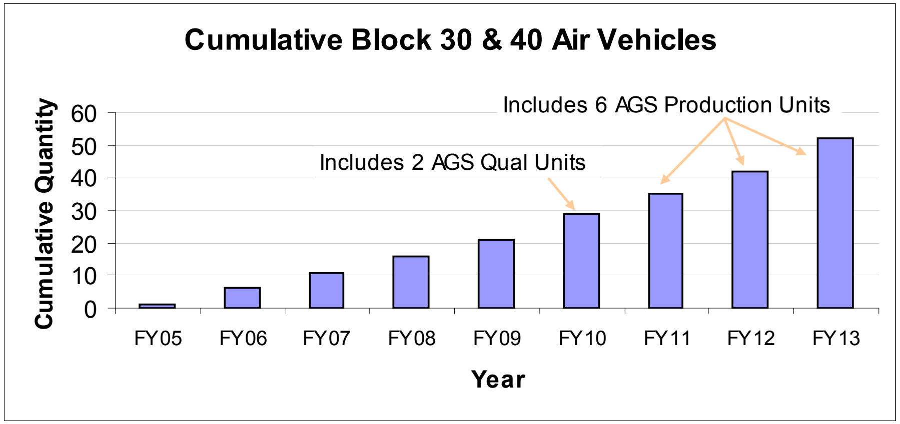
- Air Vehicle
  - Global Hawk Block 30 and 40 actuals
    - Learning curves
    - Averages
- Payload (MP RTIP)
  - Analogy to AESA
- Ground Segment
  - Analogies for hardware
  - CERs for software development
    - Manmonths
    - Burdened salaries from Eurohawk

Unadjusted Point Estimate

- Support Elements
  - Global Hawk actuals
- G&A, FCCM, & Fee
  - Global Hawk actuals

Quantity Profile

- NATO AGS's position on learning curve influenced by
  - U.S. Global Hawk production
  - BAMS development and production

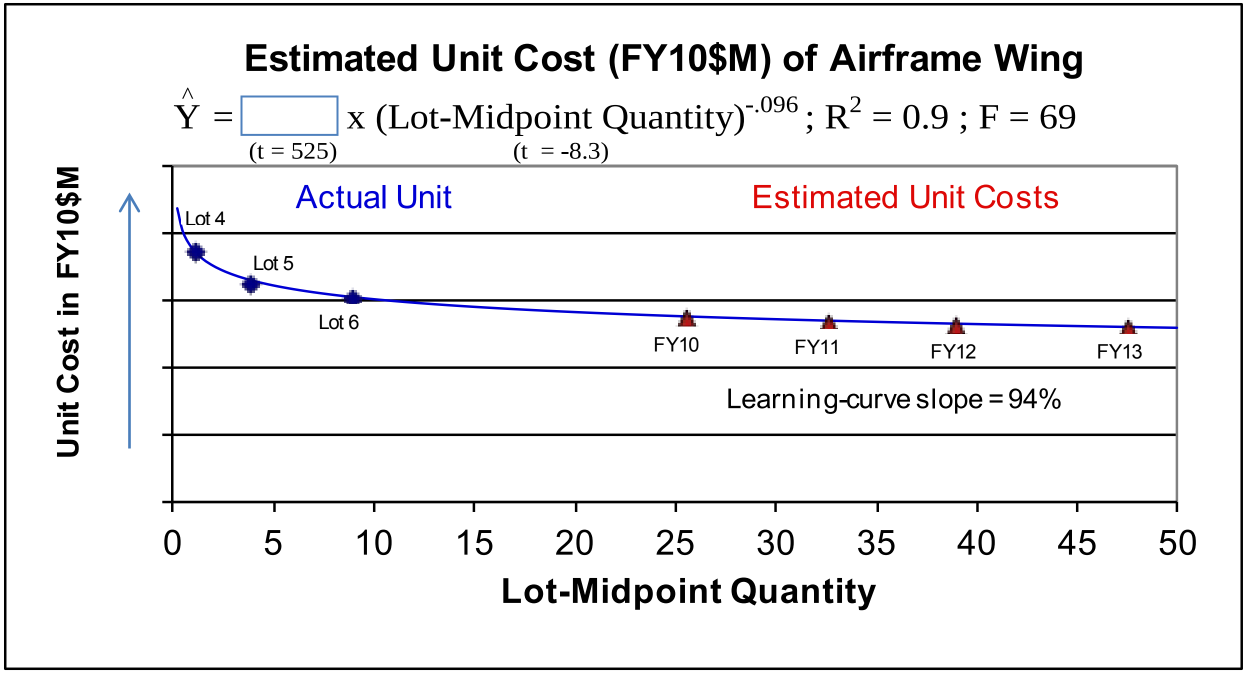


Buy Year; TOA Funding	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
U.S. Global Hawk LRIP	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9	Lot 10	Lot 11	Lot 12
Block 10 Aircraft	3	3	1									
Block 20 Aircraft			3	3								
Block 30 Aircraft				1	4	5	2	2	2	2	3	3
Block 40 Aircraft					1		3	3	2	2	2	2
Total												
DON BAMS												
SDD Units									2			
LRIP												3
APN												
NATO AGS												
Assumption #1:												
Design, Development, & Qualification									2			
Production										2	2	2

Notional: AGS schedule has slipped

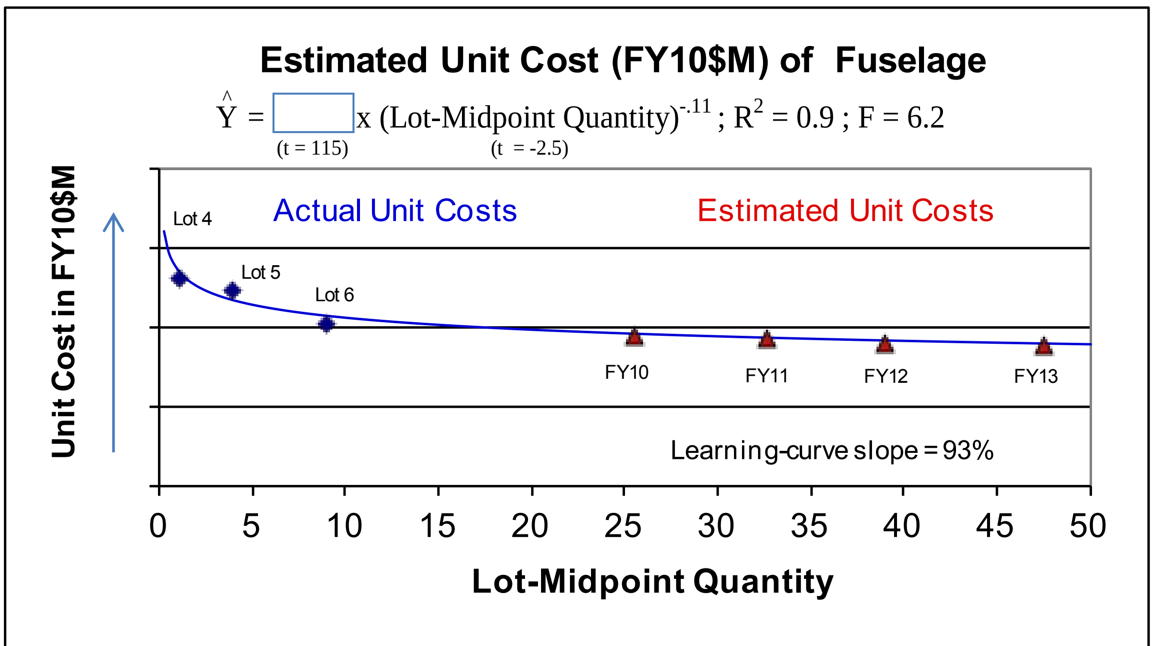
Example: Airframe Wing

- Wing fabrication, assembly, structural testing
  - Graphite & epoxy materials; high-modulus unidirectional tape
  - Vought Aircraft Industries
- Unit-learning curve; yields *median* value



Example: Airframe Fuselage

- Northrop Grumman’s Unmanned Systems Center
  - Moss Point, Mississippi
- Fabrication and mating of fore, mid, and aft of fuselage
- Cost estimated using unit-learning curve



AGS Risk Elements

Elements of Risk

- Exchange rate
  - Swing of 93% from low to high: \$0.83/€ to \$1.60/€ in 2008
- Inflation
  - Could accelerate with economic growth
- Affordability
  - Ceiling price denominated in 2007 base-year Euros
  - Many countries have dropped out
- Schedule
  - Slipped already

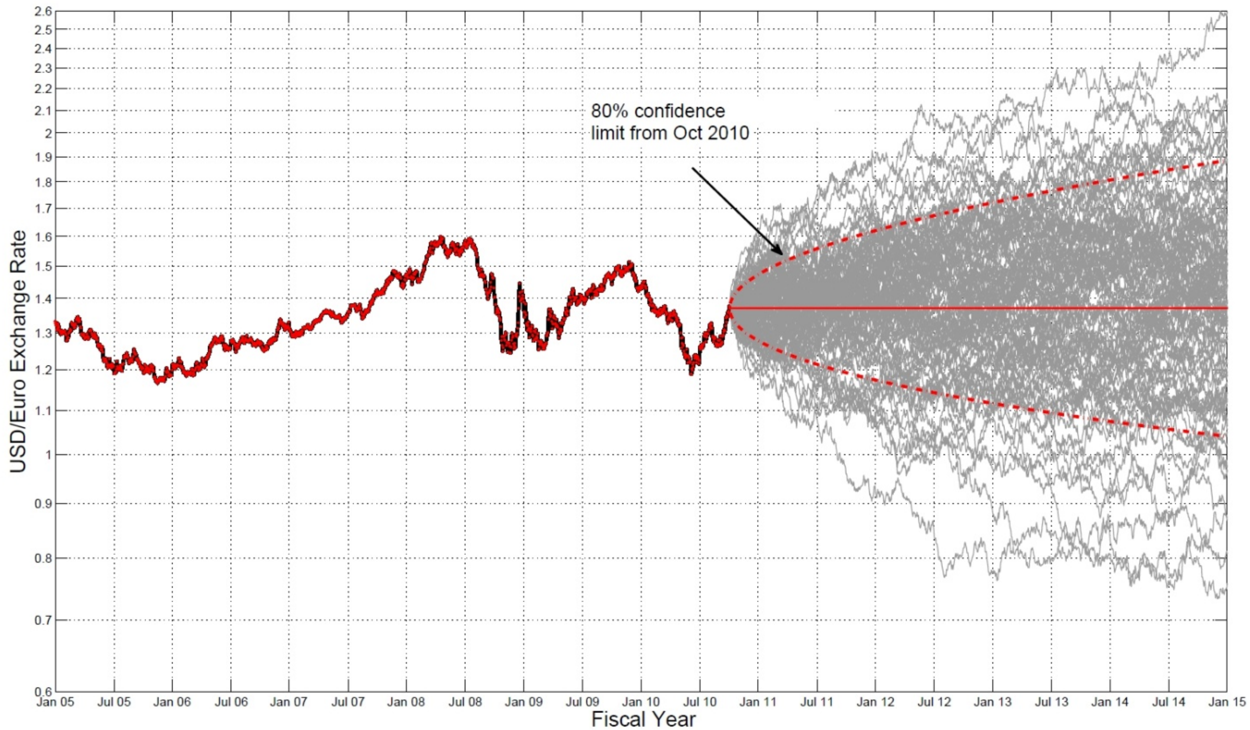
Elements of Risk

- Software development
  - x.x M ESLOC
    - Large from U.S. perspective
    - Includes requirement for user exploitation elements (mobile and transportable ground stations) covered by DCGS in U.S. for GH
- Radar
  - R&D problems could translate into higher production costs
- International Participation
  - "Best value," but each nation demands work

Exchange Rate

"Random Walk" Theory

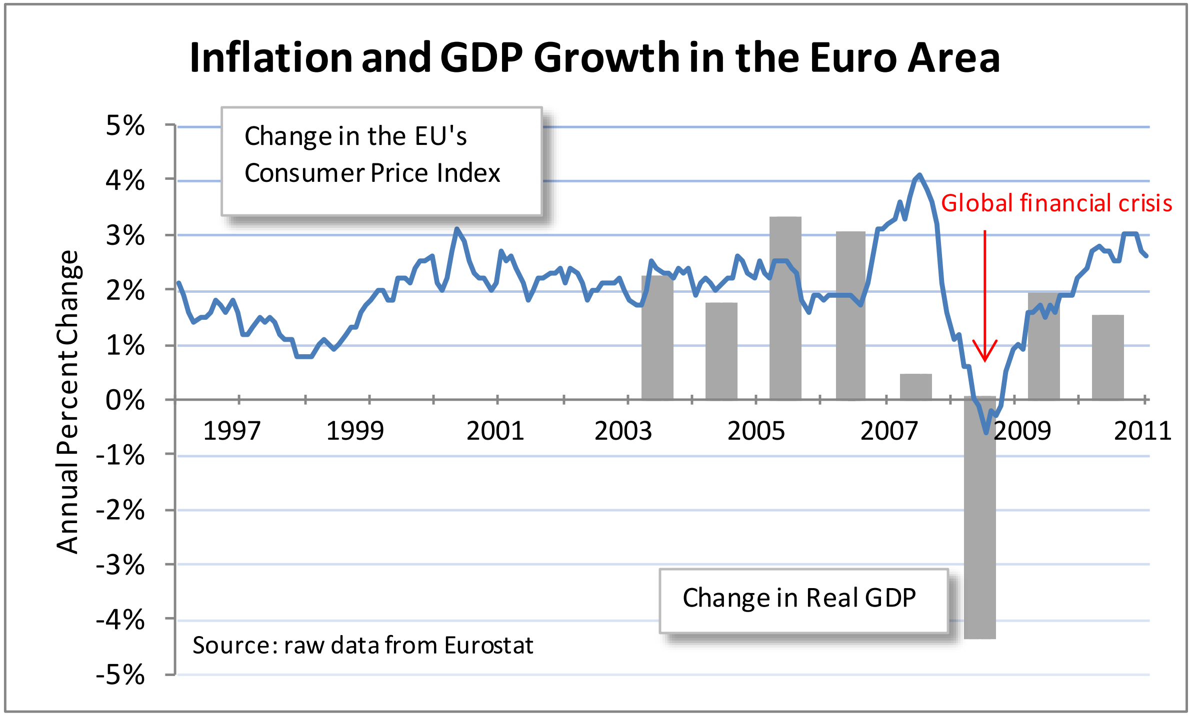
- Phrase coined by Karl Pearson in 1905
  - Trajectory based on successive random steps
  - 1st order Markov chain



Inflation Rate

Threat of Rising Rates

- If economic recovery gains traction in Europe
  - Aerospace inflation higher than in general economy
  - Baseline 3.0% per year



Affordability

FFP Ceiling in 2007 Euros

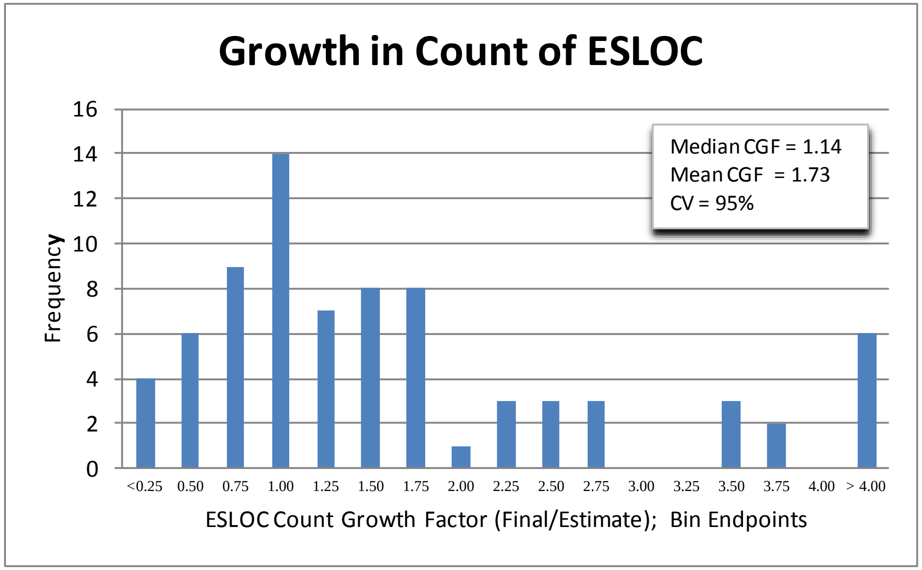
- PMOU required years to negotiate
- < 50% participation in AGS
  - Down from high of 23 out of 26 nations
- Mixed fleet scrapped in 2007
  - Modified Airbus A320 and Global Hawk UAVs
  - Too expensive
- Schedule delays increase costs in then-year US$, Canadian$, and Euros

Bulgaria, Czech Republic, Estonia, Germany, Italy, Latvia, Lithuania, Luxembourg, Norway, Romania, Slovakia, Slovenia, United States

Software Development

Highest-Risk Element

- Growth in ESLOC
  - Requirements
- Configuration Management
  - Across many companies
    - Different levels of CMMI certification
- Integration of Components
  - Software modules
  - Hardware with software
  - Other ISR assets and with intelligence gathering and analysis systems (e.g., MAGIC)



"The first 90% of the code accounts for the first 90% of the development time. The remaining 10% of the code accounts for the other 90% of the development time." *(Tom Cargill)*

Software Development

Highest-Risk Element

- Demand for "Noble Work"
  - Software versus laying coaxial cable
  - ITAR-free for ground segment
    - Knowledge gain
    - Leverage for follow-on work
    - NATO owns design but not code
- Schedule for MOB Development
  - Test facilities and equipment for software

International Participation

Prime: Northrop Grumman Integrated Systems Sector International, Inc

Northrop Grumman Integrated Systems Sector International	2nd Level Subs	3rd Level Sub Nations
	Northrop Grumman Systems Corp	Bulgaria
	Cassidian (EADS)	Czech Republic
	Selex Galileo	Estonia
	Kongsberg	Latvia
		Lithuania
		Luxemburg
		Romania
		Slovakia
		Slovenia

Potential subs to Cassidian: Retia ICZ (Czech Republic); Aktors (Estonia); Dati (Latvia); Elsis (Lithuania); Konstrukta (Slovakia); Hermes Soft Lab (Slovenia)

AGS CV and Scenarios

Choice of CV

- AGS a NATO rather than U.S. acquisition program. But,
  - Direct commercial sale to Northrop Grumman
    - Total System Performance Responsibility
  - Based on U.S. Global Hawk
  - Most of costs to be incurred in U.S.
- Many risk elements
  - Therefore, robust CV of 51% used
    - Quantity-adjusted in then-year dollars (and Euros)
    - Based on complete sample at MS B

Scenarios

- Baseline
  - Mostly likely
- Pessimistic
  - Unfavorable yet plausible
- Resource-Constrained
  - To meet ceiling price

Scenario Parameters

Baseline

- Exchange rate: $1.35/Euro
- Inflation: 3% per annum
- Quantities: 8 UAVs and 15 ground-segment vehicles
- Schedule: contract award by end of CY2011
- 91% learning on radar
- No impact for building in NATO environment
- No growth in ESLOC

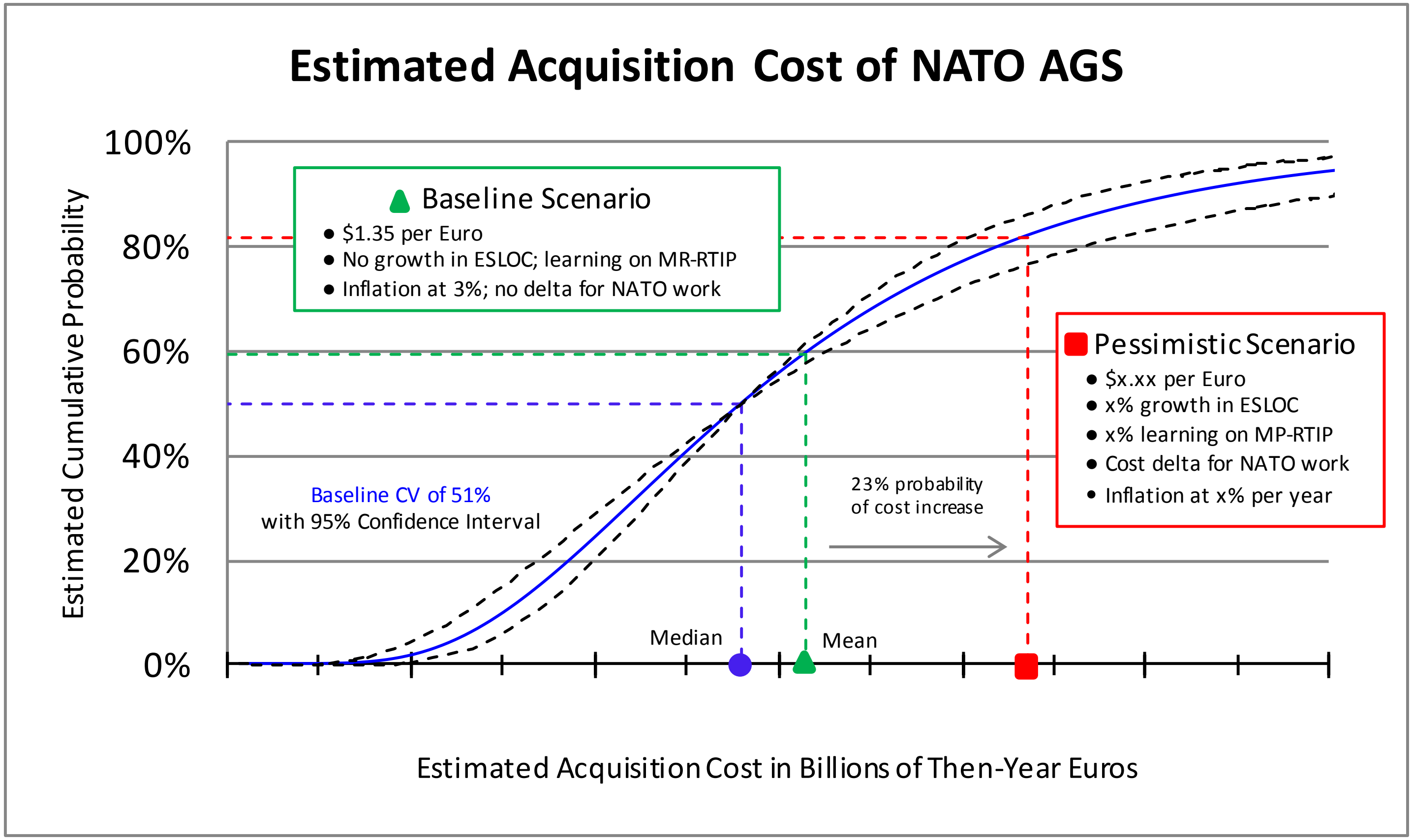
Pessimistic

- X% deviation in exchange rate
- Increase in the rate of inflation of xxx basis points per annum
- No change in quantities
- Slip in schedule
- Decrease in learning on radar
- Increase in SE/PM due to multi-national environment
- X% growth in ESLOC

Resource-Constrained

- Quantities decreased to fit within ceiling price

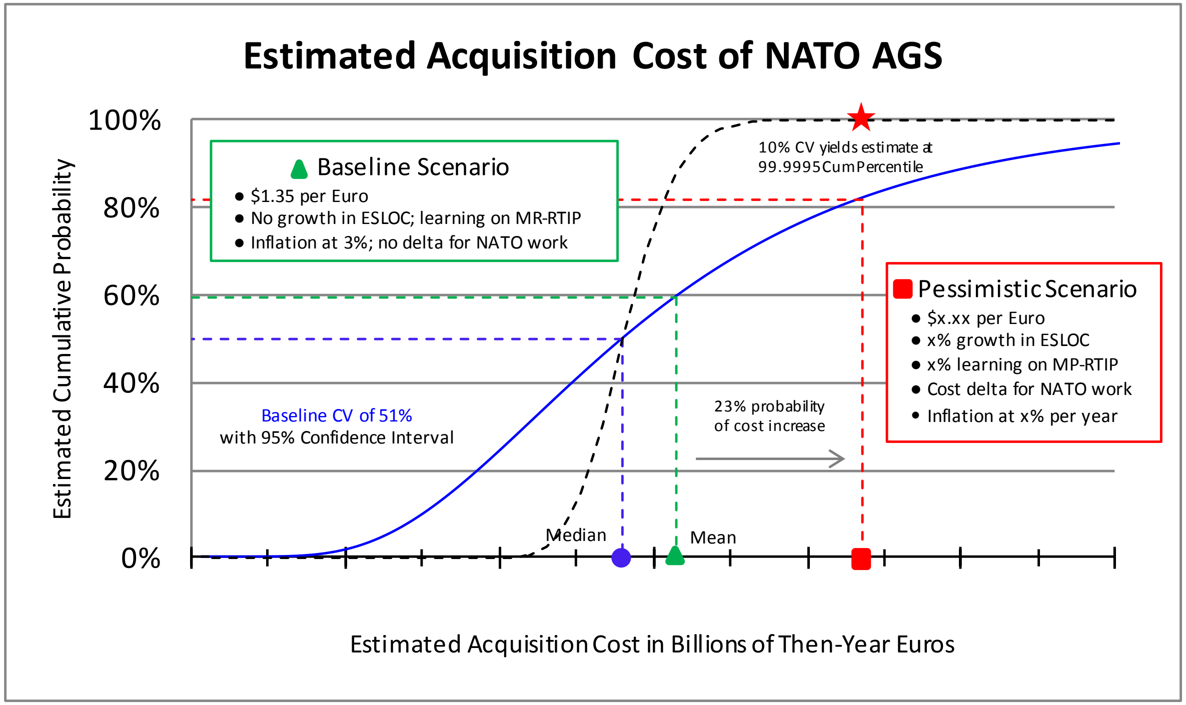
S-Curve for NATO AGS



Cost values not displayed because of business sensitivity

S-Curve for NATO AGS

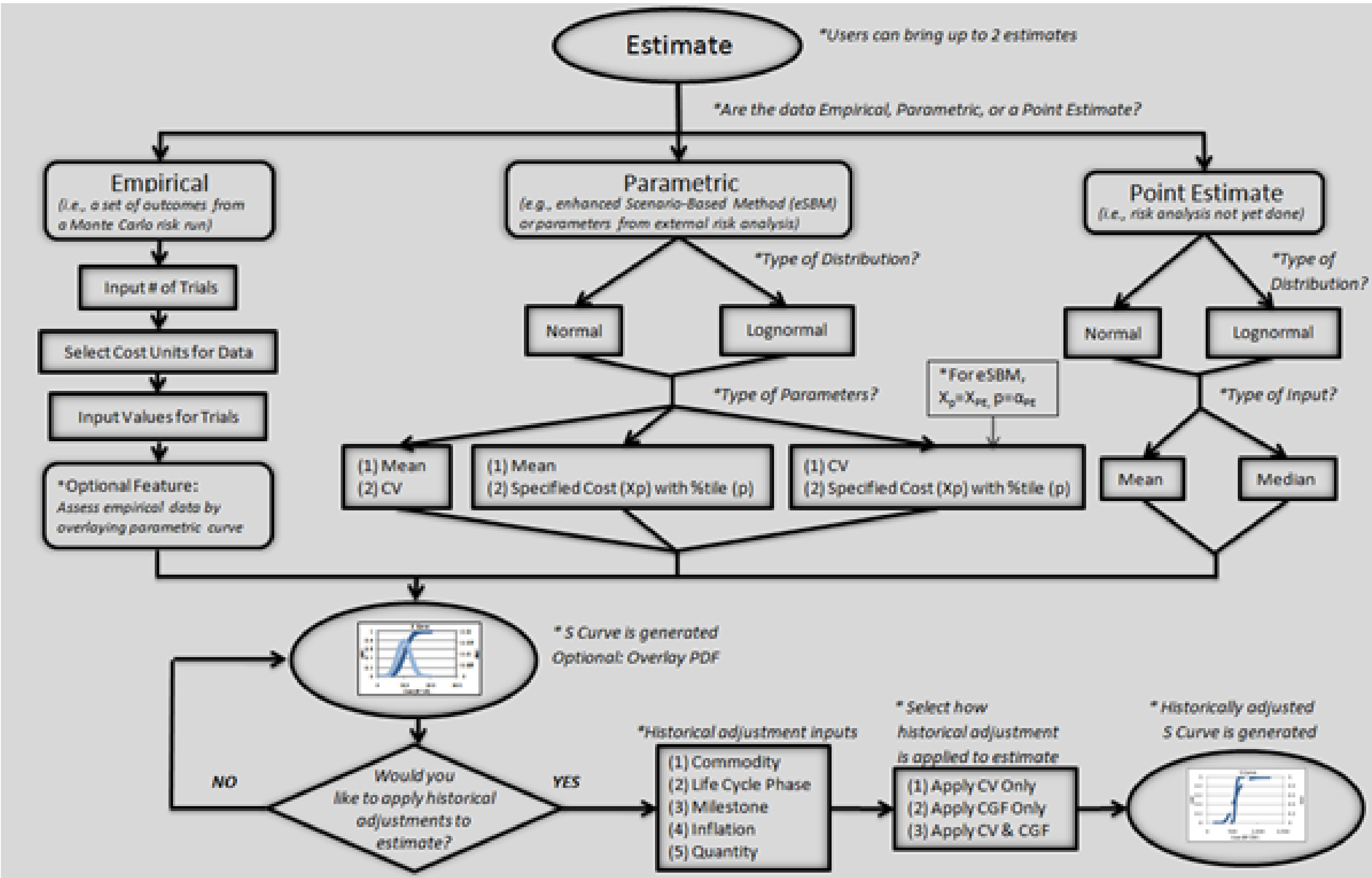
- Hypothetical Option
  - CV of 10%
  - Pessimistic estimate
    - Five in one million chance of costs reaching that level or higher!
  - Deceives stakeholders
    - Underestimates probability
- Take away
  - Essential to use benchmark data
  - Perform "deep dive"



Cost values not displayed because of business sensitivity

S-Curve Tool*

Supports both Monte Carlo Simulation and eSBM



"Testing S-Curves for Reasonableness: The NCCA S-Curve Tool," Coleman, Braxton, Lee, Flynn, SCEA 2011

S-Curve Tool

- Allows practitioners to
  - Perform internal V&V
    - Compare their estimated S-curves to curves using benchmark CVs and CGFs
  - Perform assessments and reconciliations
    - Compare ICE and Program Office S-curves
  - Generate graphics

- eSBM POC
  - Dr. Paul Garvey, MITRE
- Tool POCs
  - Mr. Peter Braxton
  - Mr. Richard Lee
  - Dr. Brian Flynn
  - Mr. Ben Breaux
- Tool and eSBM paper on NCCA's website
  - At www.ncca.navy.mil

Backup

CVs: Calculation Issue

- "… a central issue of risk analysis:
  - We are trying to characterize **within-program** risk
    - But "Cost is an unrepeatable experiment," and we only ever get one observation for each historical program
  - Thus, we are stuck using data from **cross-program** risk
  - We must cleverly devise a model that explains the former, while using historical data from the latter"

"The Perils of Portability: CGFs and CVs,"
Peter J. Braxton, Richard C. Lee, Kevin M. Cincotta, Jack Smuck, Megan Guild, and Richard L. Coleman;
SCEA/ISPA Conference 2011

CGFs as Cost Outcomes

Sequence of 50 BY$ CGFs: $CE/BE_{1,1984}$, $CE/BE_{2,1978}$, $CE/BE_{3,1986}$, …, $CE/BE_{50,2004}$
where i,j = observation number, base year of numerator and denominator

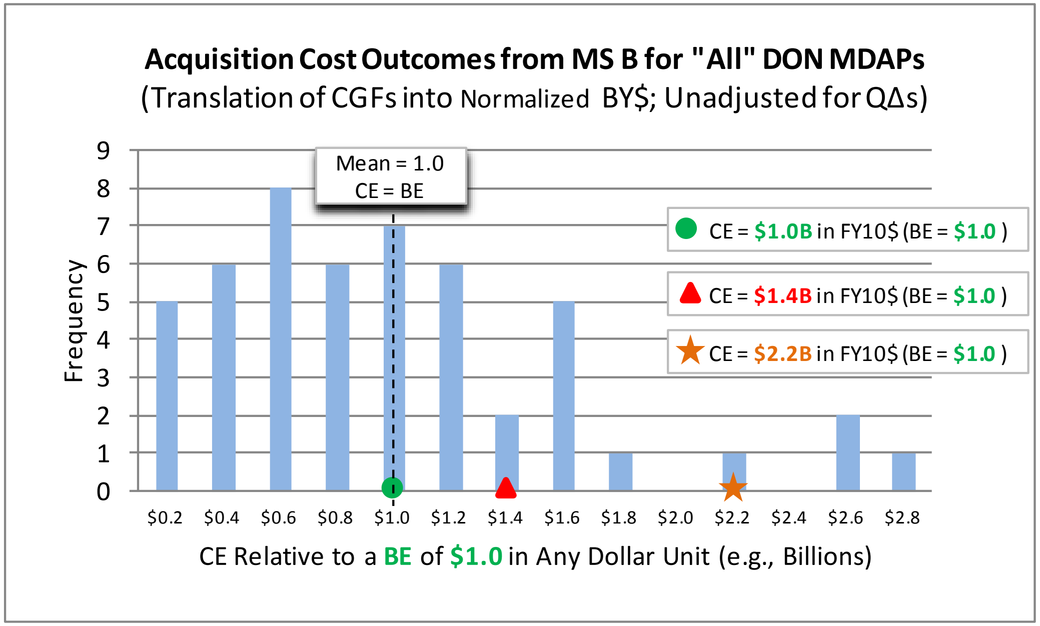
Different raw indices for different SAR base years; purely conceptual since ratios won't change

Steps:

- Inflate each ratio to common year (e.g., FY2010)

Pedagogical aid

- Normalize CGFs to mean of 1.0
  - $CE = $BE at the mean
- Each $CE now interpretable as a cost outcome per dollar of $BE
  - Same units of measurement
  - Same year dollars
- CV is unchanged
  - Computation also holds for BY$ quantity adjustments



CV of costs & CGFs = 63%

Desirable Statistical Properties:

CV independent of base year

CV independent of unit of measurement

Questionable Statistical Property:

CV invariant with respect to program size

Military Reading List

Nonfiction

- With the Old Breed, E. B. Sledge
  - Wall Street Journal calls this book one of the "top five" ever in describing any battle in the 20th century. A mortarman (MOS 0341) in the First Marine Division gives his account of fighting on the front lines in the Pacific campaigns of Peleliu and Okinawa.
- Unbroken, Laura Hillenbrand
  - The author of "Seabiscuit" chronicles the ordeals of Louis Zamperini, an Olympic miler, who survived incredible hardship and torture when his B-24 Liberator crashed in the South Pacific in WW II.
- Ambush Alley, Tim Pritchard
  - According to many, "the most extraordinary battle of the Iraq war. "
- Inside Delta Force, Eric Haney
  - A gripping account of the formation, operation, and skills of America's elite counter-terrorism unit.
- Horse Soldiers, Doug Stanton
  - U.S. Special Forces defeat the Taliban in Afghanistan shortly after 9/11.

Fiction

- Ender's Game, Orson Scott Card
  - Aliens have nearly destroyed the human race in two attacks. Our survival now rests entirely in the hands of a young genius, Ender Wiggin.
  - Officially recommended as "professional reading" by the U.S. Marine Corps.
  - I picked this one up at Quantico.