Development and Application of CV Benchmarks

Naval Center for Cost Analysis
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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
- Secular Invariance
  - CVs steady long-term

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
  - "Fischer" index = square root of the product of the first two
- CV deltas insignificant (.02 and .04 spreads in BY$ & TY$ for ships & submarines) 5

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 Baseline 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
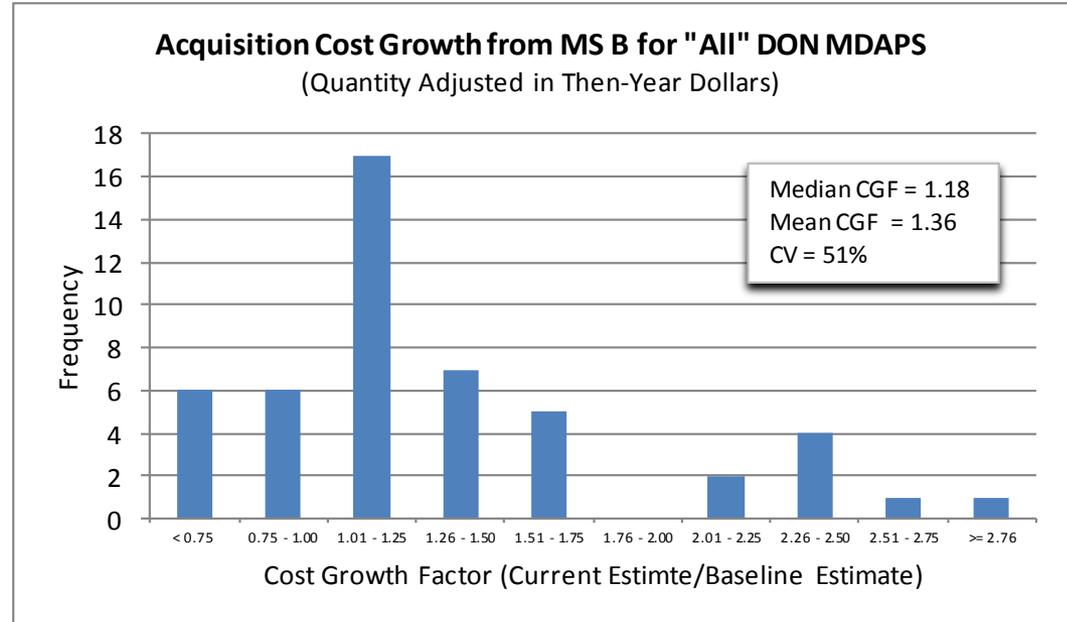 - Base Year$
  - Then Year $
- Date of last SAR

F/A-18 E/F
JSOW
Expeditionary Fighting Vehicle (formerly AAAV)
MIDS - Low Volumne Terminal (LVT)
Cooperative Engagement
H-1 UPGRADES
MH-60S
TACTICAL TOMAHAWK
MH-60R
E-2D Advanced Hawkeye
EA-18G (Electronic Attack)
COBRA JUDY REPLACEM
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 (Bl
TOMAHAWK Baseline Im
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)

Statistics		(Without Qty Adjustment)		(Quantity Adjusted)	
		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

Cost Growth Factors & CVs for All DON MDAPs at MS B for 1969 & Later; n = 50

Acquisition Cost Growth from MS B for "All" DON MDAPS
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.18
Mean CGF = 1.36
CV = 51%

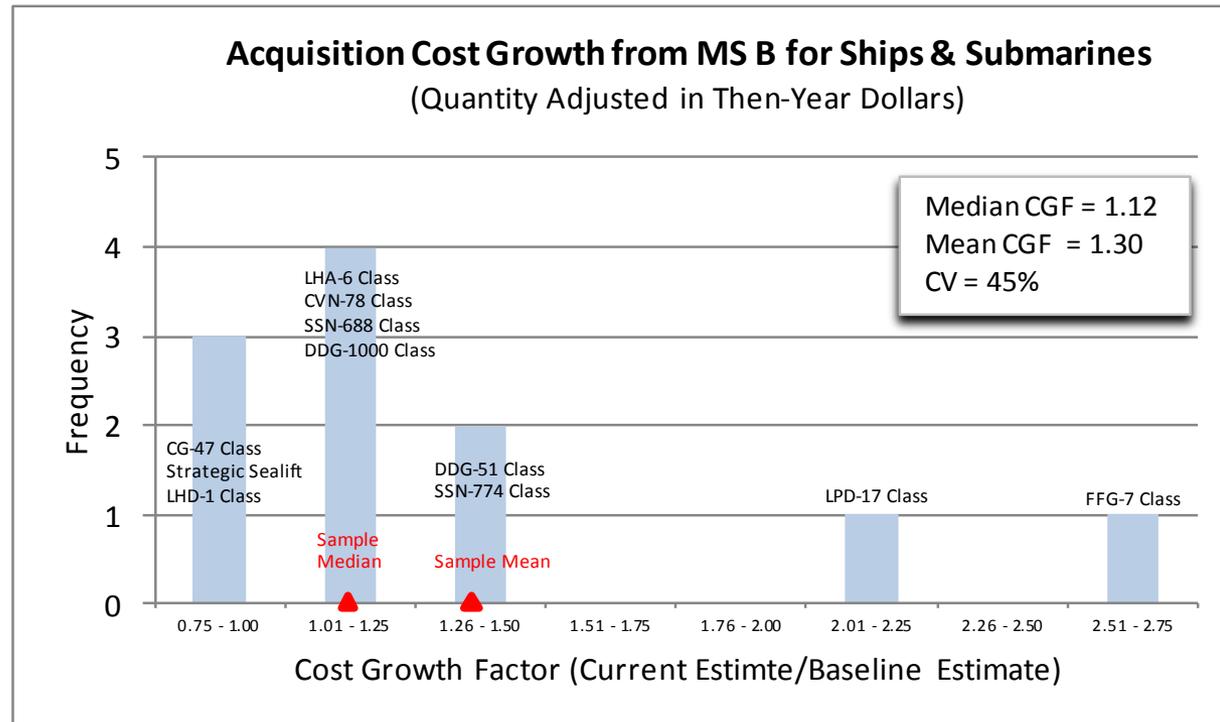Cost Growth Factor (Current Estimte/Baseline Estimate)

MS B: Ships and 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					
Statistics		(Without Qty Adjustment)		(Quantity Adjusted)	
		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

Acquisition Cost Growth from MS B for Ships & Submarines
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.12
Mean CGF = 1.30
CV = 45%

LHA-6 Class
CVN-78 Class
SSN-688 Class
DDG-1000 Class

CG-47 Class
Strategic Sealift
LHD-1 Class

DDG-51 Class
SSN-774 Class

LPD-17 Class

FFG-7 Class

Sample Median

Sample Mean

Frequency

Cost Growth Factor (Current Estimte/Baseline Estimate)

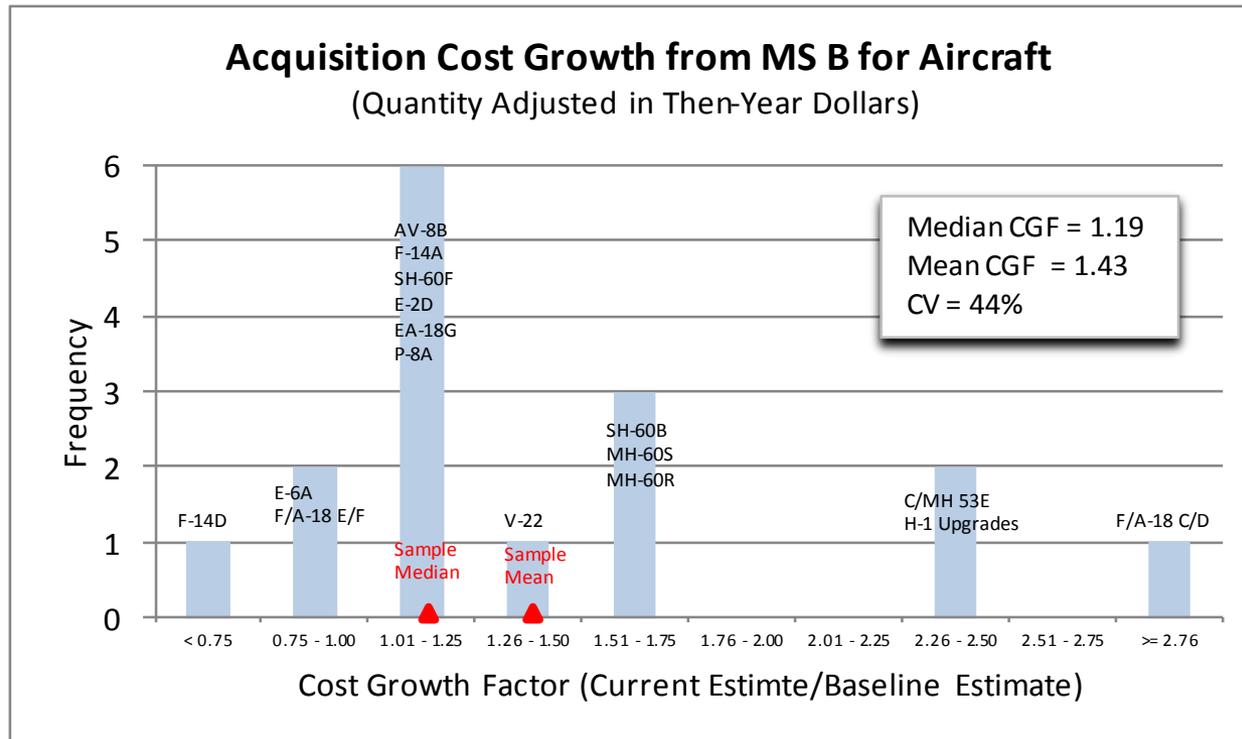0.75 - 1.00   1.01 - 1.25   1.26 - 1.50   1.51 - 1.75   1.76 - 2.00   2.01 - 2.25   2.26 - 2.50   2.51 - 2.75

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

Acquisition Cost Growth from MS B for Aircraft
(Quantity Adjusted in Then-Year Dollars)

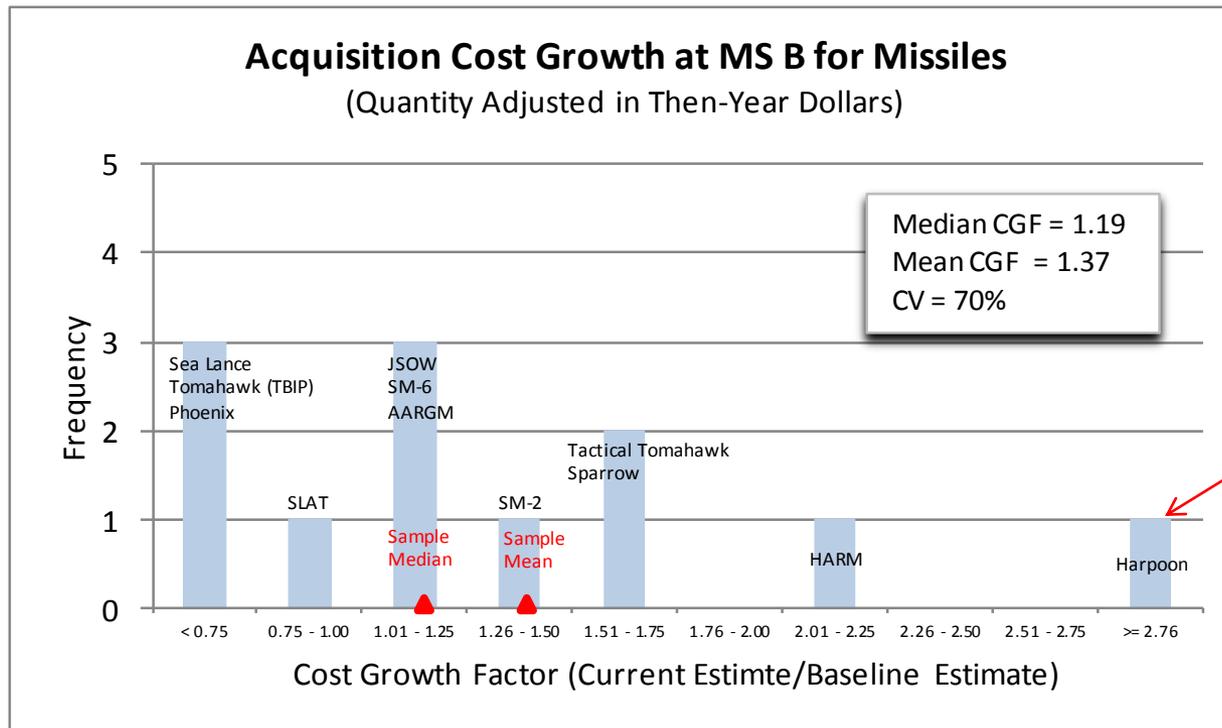Median CGF = 1.19
Mean CGF = 1.43
CV = 44%

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				
		(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics		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

Acquisition Cost Growth at MS B for Missiles
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.19
Mean CGF = 1.37
CV = 70%

Without HARPOON (CGF = 3.96), CV = 47%

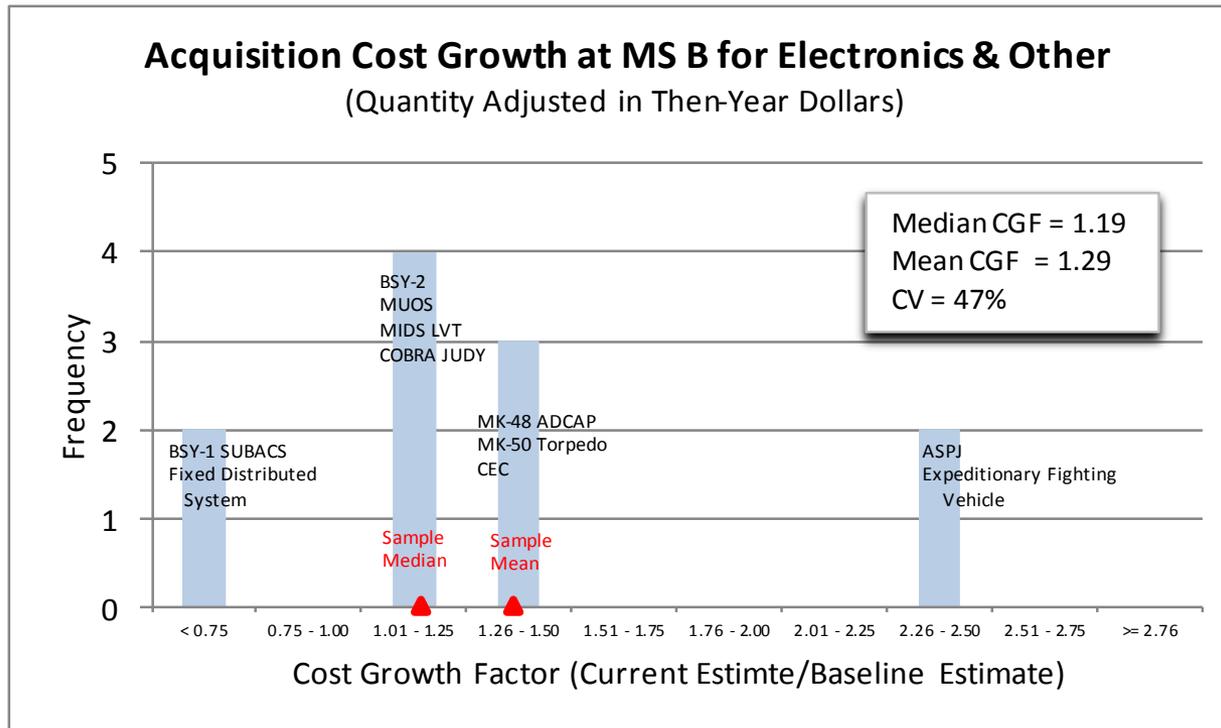Frequency axis vs Cost Growth Factor (Current Estimte/Baseline Estimate)

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

Acquisition Cost Growth at MS B for Electronics & Other
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.19
Mean CGF = 1.29
CV = 47%

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Hypothesis Testing for MS B

Hypothesis

- Homogeneity of CGF means

  - H_o: $\mu_1 = \mu_2 = ... = \mu_k$, 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

Means & Spreads of CGFs from MS B
(Quantity Adjusted in Then-Year$)

Cost Growth Factor (y-axis: 0.0 to 4.5)

Sample $\sigma^2 = .34$ — Ships & Subs: 1.30

Sample $\sigma^2 = .40$ — Aircraft: 1.43

Sample $\sigma^2 = .92$ — Missiles: 1.37

Sample $\sigma^2 = .36$ — Elex & Other: 1.29
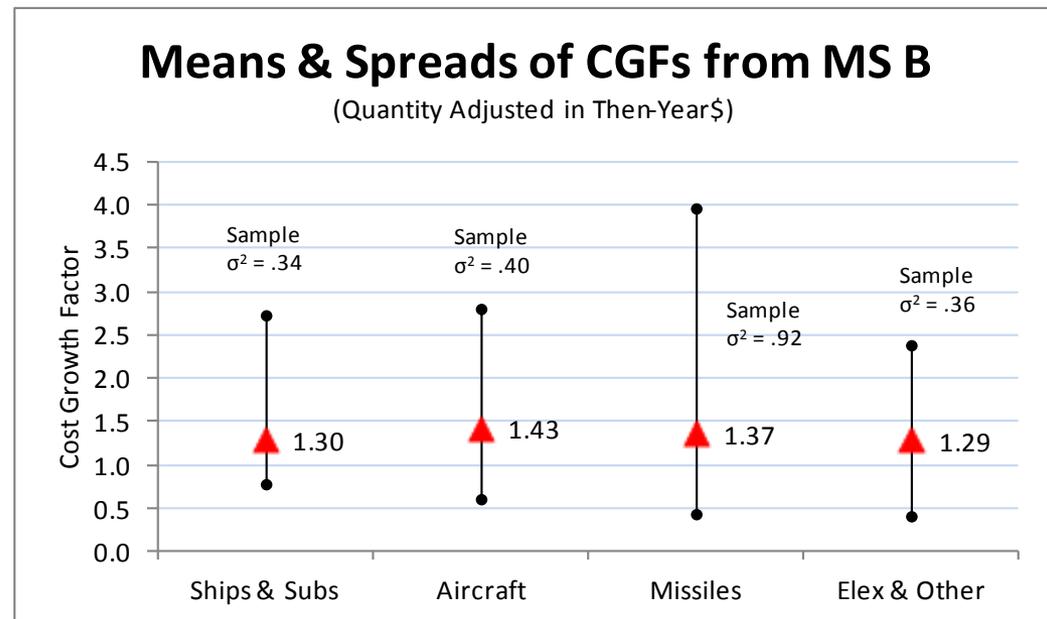
Hypothesis Testing for MS B

Hypothesis

- Homogeneity of CGF variances

  - H_o: $\sigma^2_1 = \sigma^2_2 = ... = \sigma^2_k$, 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
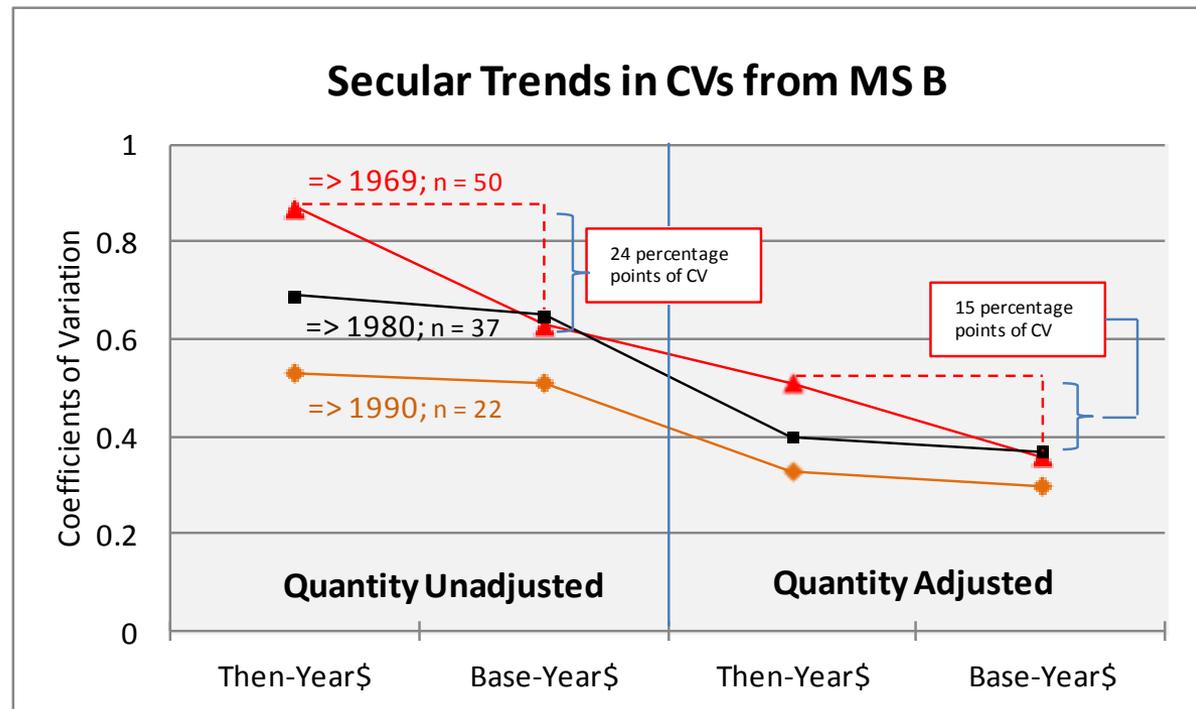
Other Findings for MS B

- 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

Quantity- and Inflation-Adjusted CVs from MS B
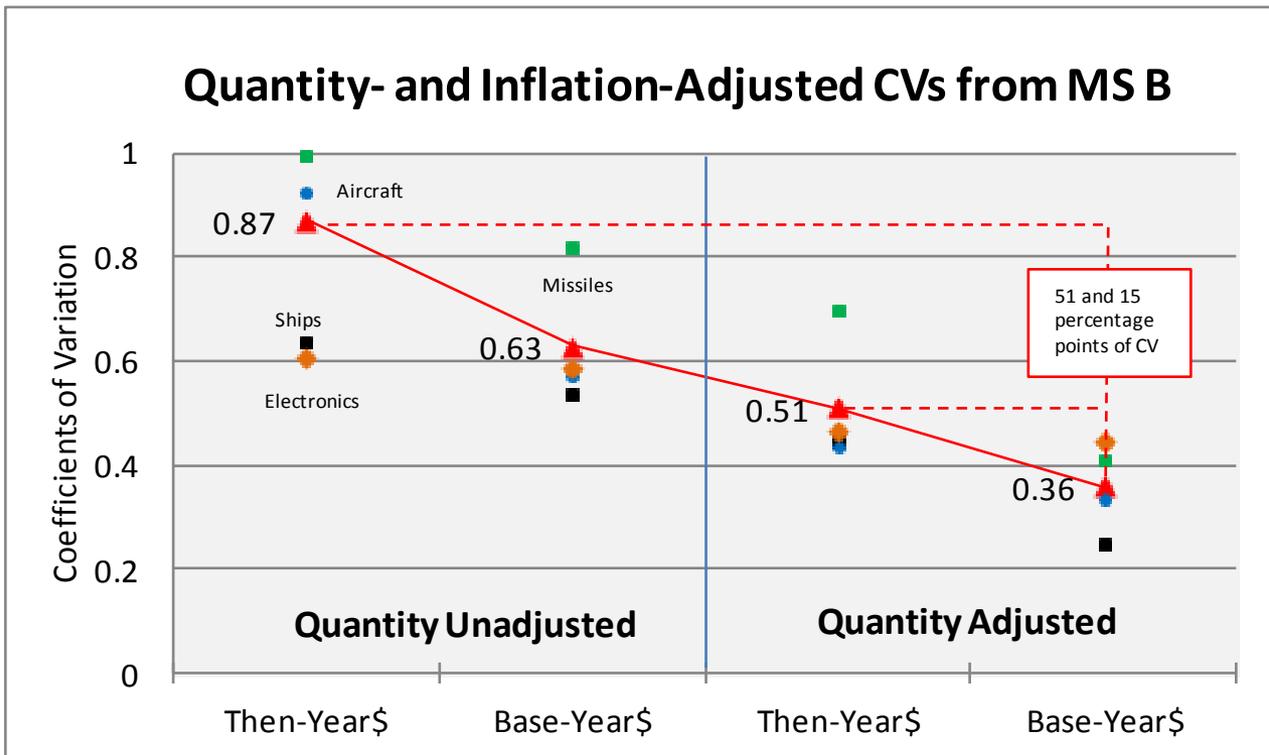
Other Findings for MS B

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

Secular Trends in CVs from MS B

=> 1969; n = 50

24 percentage points of CV

=> 1980; n = 37

15 percentage points of CV

=> 1990; n = 22

Coefficients of Variation

Quantity Unadjusted

Quantity Adjusted

Then-Year$ Base-Year$ Then-Year$ Base-Year$

Sample Data at MS C

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 Reactivation
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 Volumne 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

CVs for Total Acquisition Cost: MS B and MS C

Acquisition Cost Growth from MS C for "All" DON MDAPS
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.07
Mean CGF = 1.10
CV = 26%

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
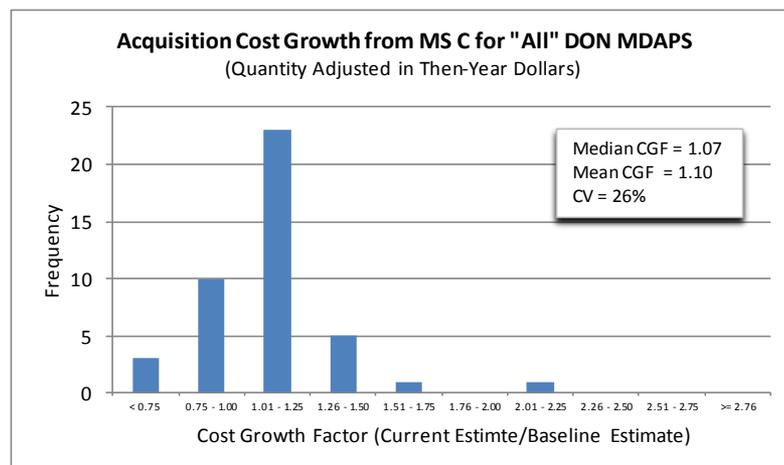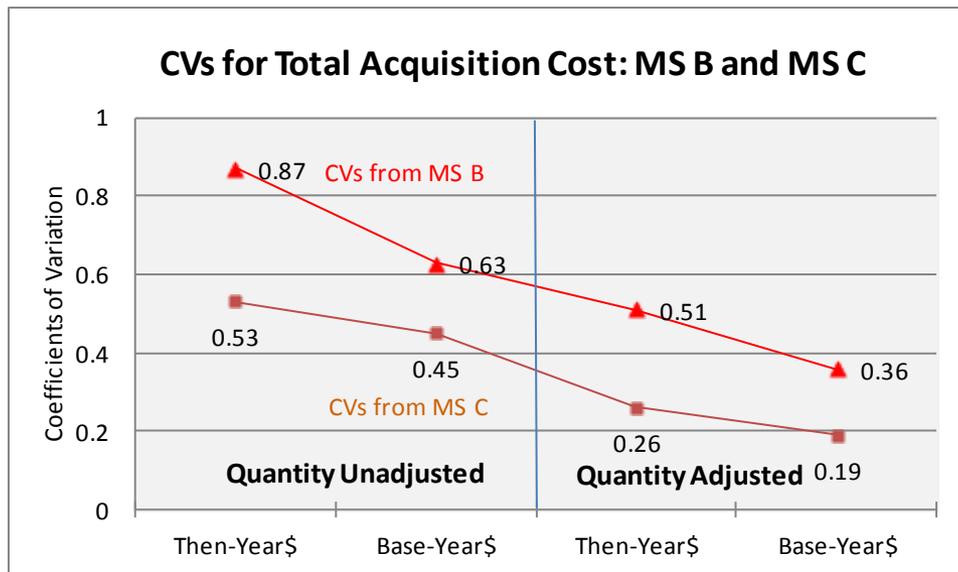
MS C: Ships and Submarines

Comparison with "All DON"

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

		(Without Qty Adjustment)		(Quantity Adjusted)	
Statistics		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

Cost Growth Factors & CVs for Ship & Sub MDAPs at MS C; n = 19

Acquisition Cost Growth from MS C for Ships & Submarines
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.05
Mean CGF = 1.07
CV = 22%

CVN-71 (1 Ship)
T-AKE Class
CVN-74/75
MCM-1 Class
CVN-76 (1 Ship)
MHC-51 Class
T-AGOS
CVN-68 Class (2 ships)
CVN-68 Class (1 ship)

CVN-72/73
LSD-41 Class
LSD-49 Class
TAO-187 Class
LCACs
Battleship React

DDG-51 Class
AOE-6 Class

Trident II Subs

Sample Median and Mean

SSN-21 & AN/BSY-2

Frequency

Cost Growth Factor (Current Estimte/Baseline Estimate)

< 0.75   0.75 - 1.00   1.01 - 1.25   1.26 - 1.50   1.51 - 1.75   1.76 - 2.00   2.01 - 2.25
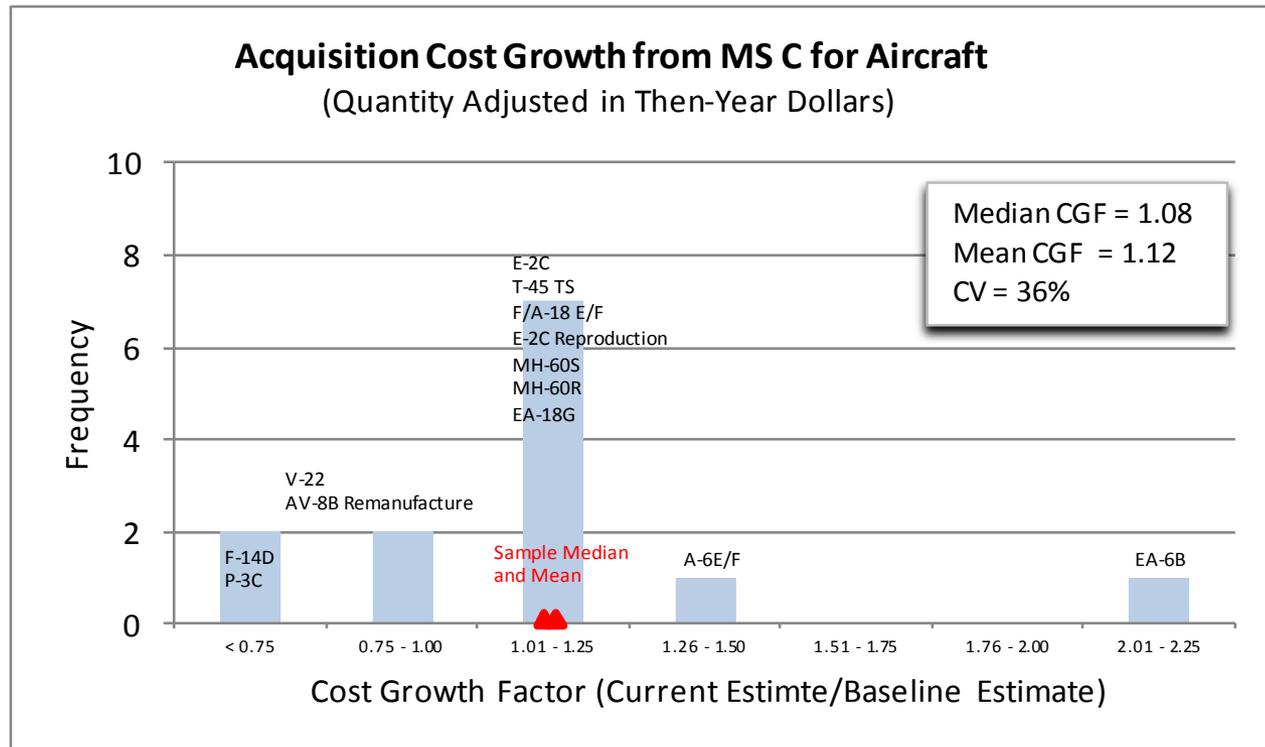
MS C: Aircraft

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

Acquisition Cost Growth from MS C for Aircraft
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.08
Mean CGF = 1.12
CV = 36%

E-2C
T-45 TS
F/A-18 E/F
E-2C Reproduction
MH-60S
MH-60R
EA-18G

V-22
AV-8B Remanufacture

F-14D
P-3C

Sample Median and Mean

A-6E/F

EA-6B

Frequency

Cost Growth Factor (Current Estimte/Baseline Estimate)

< 0.75   0.75 - 1.00   1.01 - 1.25   1.26 - 1.50   1.51 - 1.75   1.76 - 2.00   2.01 - 2.25
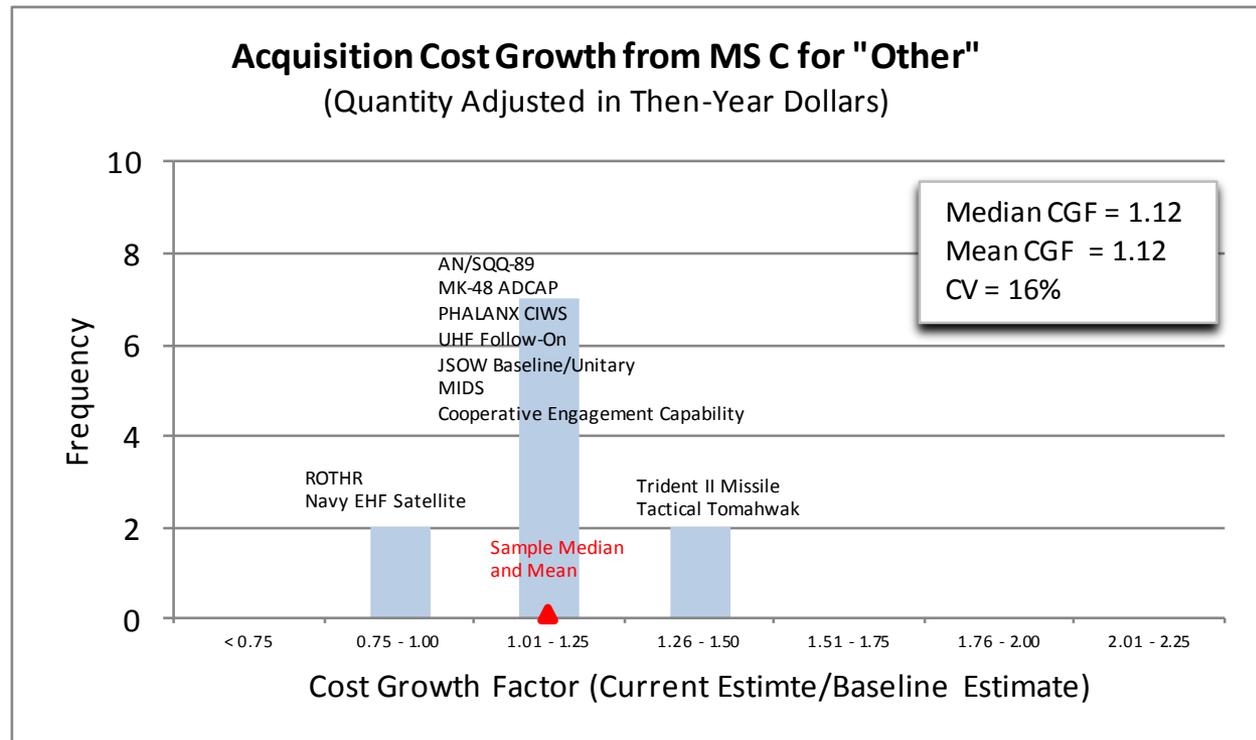
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MS C: "Other"

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

Acquisition Cost Growth from MS C for "Other"
(Quantity Adjusted in Then-Year Dollars)

Median CGF = 1.12
Mean CGF = 1.12
CV = 16%

AN/SQQ-89
MK-48 ADCAP
PHALANX CIWS
UHF Follow-On
JSOW Baseline/Unitary
MIDS
Cooperative Engagement Capability

ROTHR
Navy EHF Satellite

Trident II Missile
Tactical Tomahwak

Sample Median and Mean

Frequency (y-axis: 0, 2, 4, 6, 8, 10)

Cost Growth Factor (Current Estimte/Baseline Estimate)

x-axis: < 0.75, 0.75 - 1.00, 1.01 - 1.25, 1.26 - 1.50, 1.51 - 1.75, 1.76 - 2.00, 2.01 - 2.25

Hypothesis Testing for MS C

Hypothesis

- Homogeneity of CGF means

  - H_o: $\mu_1 = \mu_2 = ... = \mu_k$, 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

Means & Spreads of CGFs from MS C
(Quantity Adjusted in Then-Year$)

Sample $\sigma^2 = .06$
Sample $\sigma^2 = .16$
Sample $\sigma^2 = .03$

Ships & Subs — 1.07
Aircraft — 1.12
Other — 1.12

Cost Growth Factor
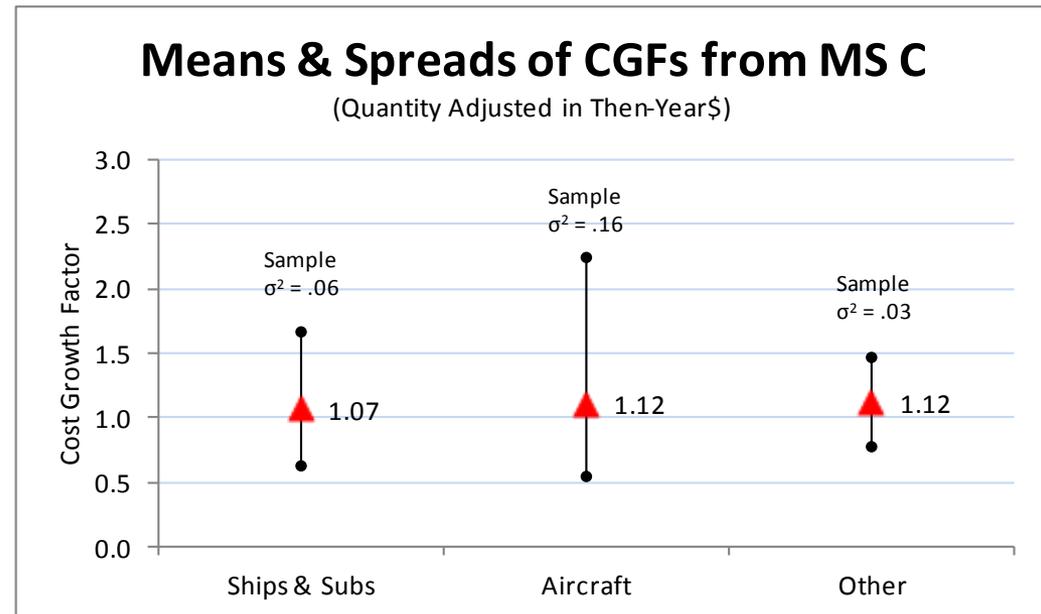
Hypothesis Testing for MS C

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

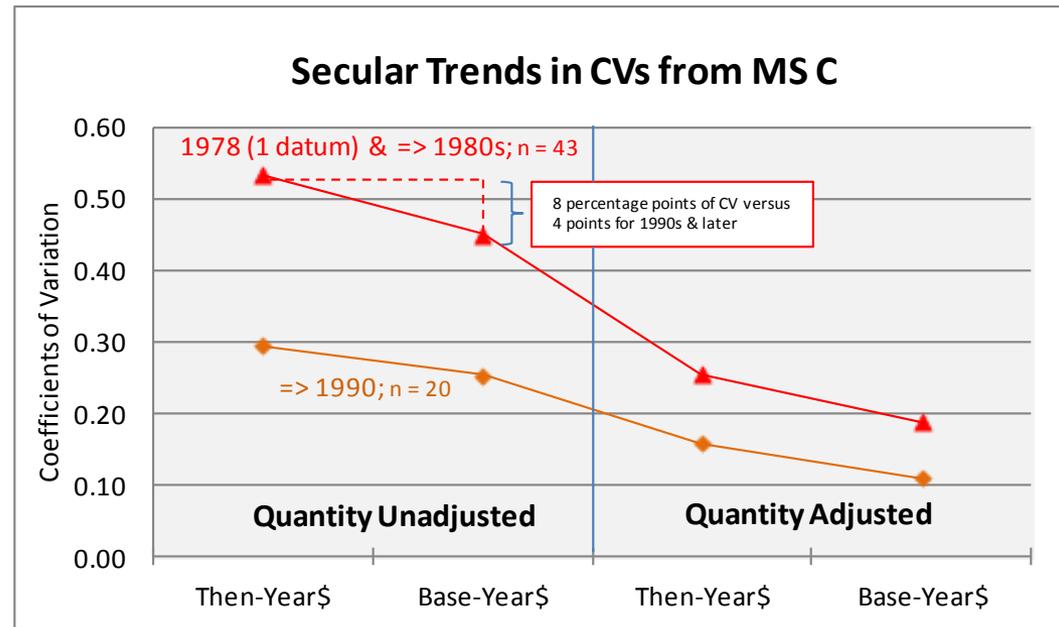| Sample Pairwise F Statistics			
Platforms	Ships & Subs	Aircraft	Other
Ships and Subs		2.792	1.677
Aircraft			4.682
Other			

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
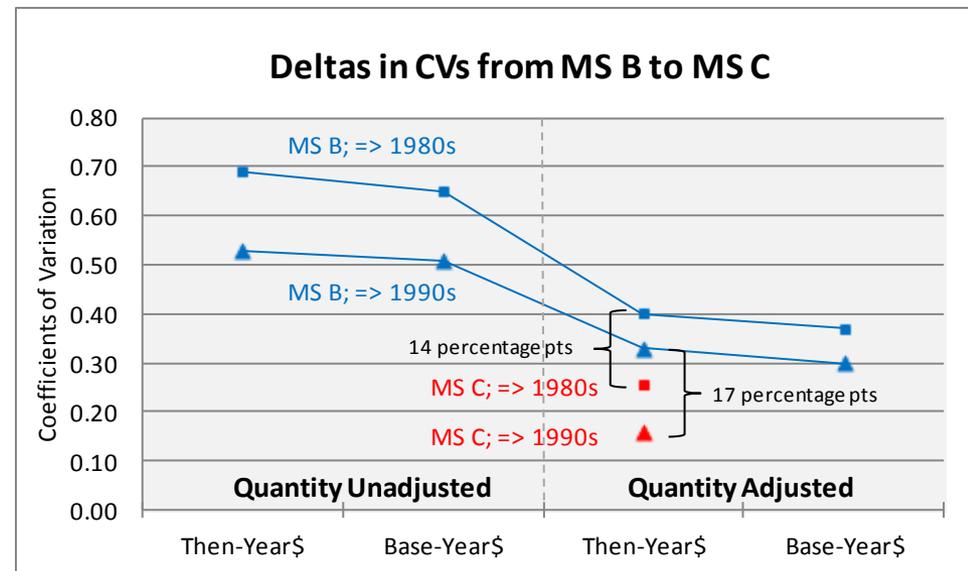
Secular decline in CVs

- 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

Secular Trends in CVs from MS C

1978 (1 datum) & => 1980s; n = 43

8 percentage points of CV versus 4 points for 1990s & later

=> 1990; n = 20

Coefficients of Variation

0.60
0.50
0.40
0.30
0.20
0.10
0.00

Quantity Unadjusted   **Quantity Adjusted**

Then-Year\$ Base-Year\$ Then-Year\$ Base-Year\$

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

Cost Growth Factors at MS A for 7 DON MDAPS
(Quantity Adjusted in Then-Year Dollars)

Deltas in CVs from MS B to MS C
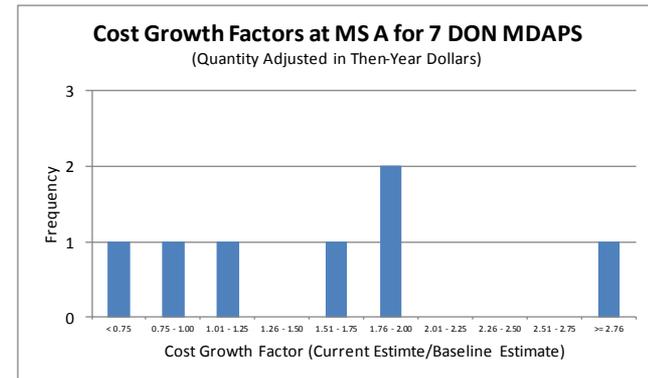
Summary of Findings

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

- Secular Invariance
  - 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
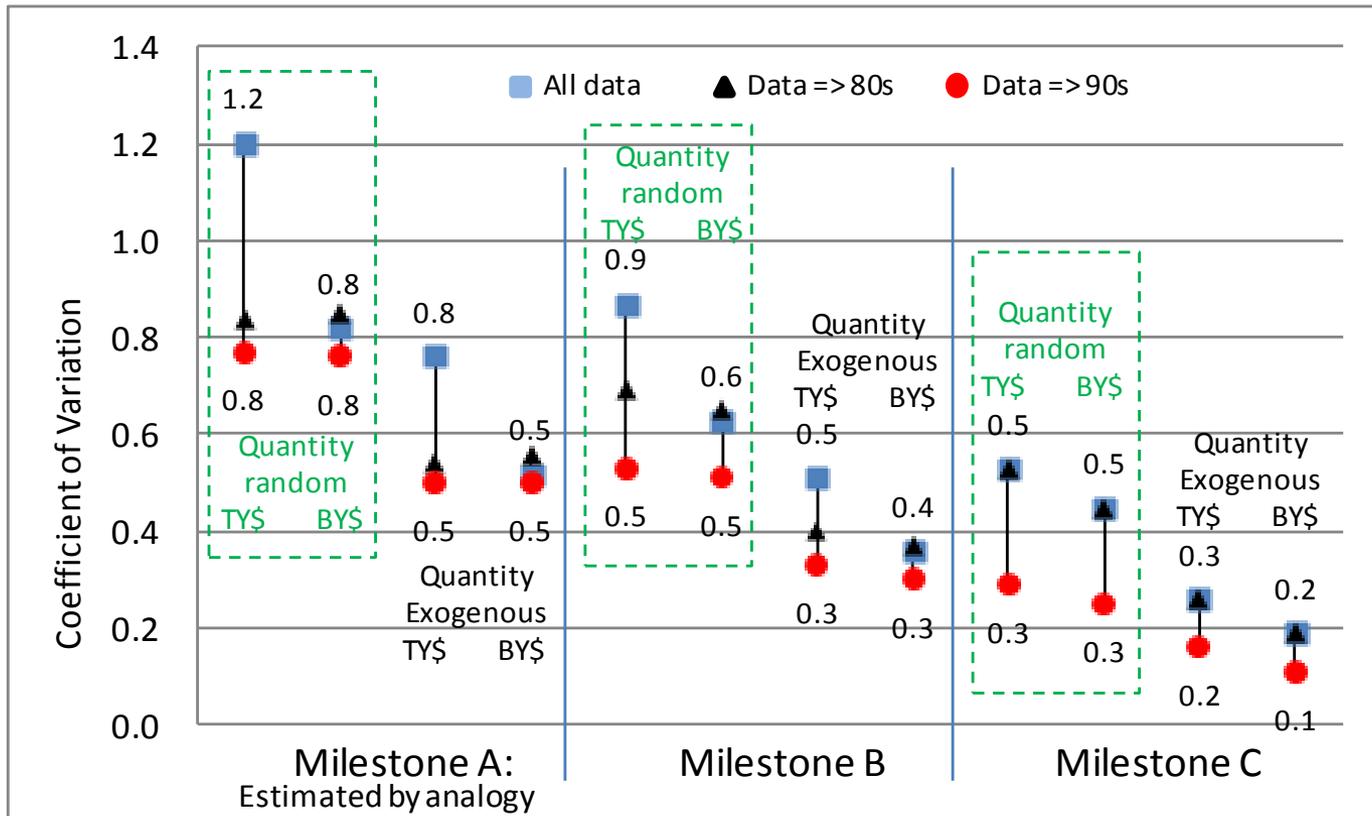
Options for "trigger values" requiring an explanation
- Use historical range
- Use fixed percentage from endpoints
- Use confidence intervals

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

95% Confidence Intervals for CVs
(Quantity-Adjusted; TY$; Data => 1980s)

Coefficient of Variation

Estimated from historical data

Estimated by analogy

	MS A	MS B	MS C
Upper	0.74	0.54	0.34
Lower	0.41	0.31	0.21
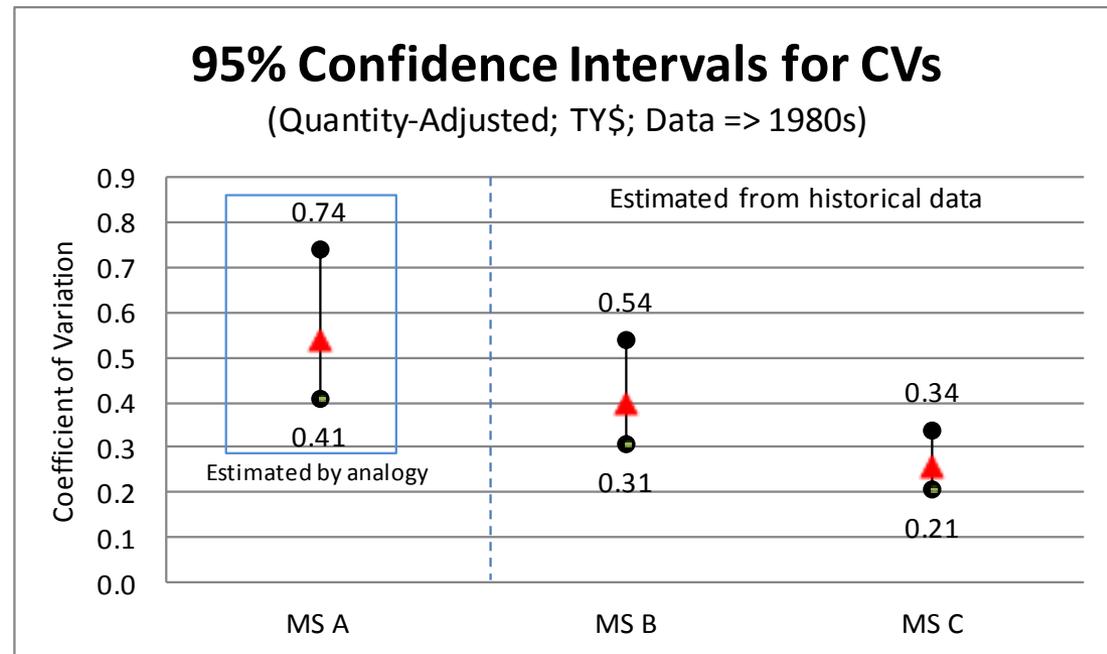
Case Study #1

NATO Alliance Ground Surveillance System
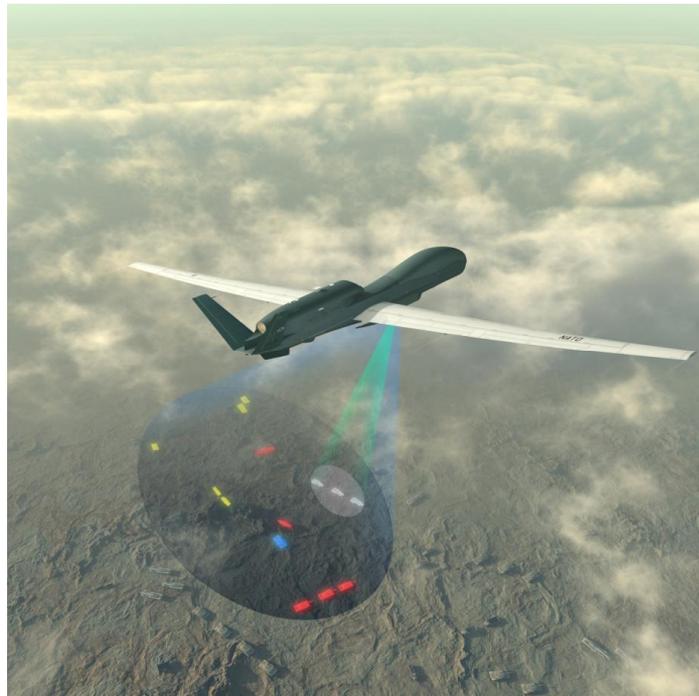
NATO AGS Program

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

eSBM

START

1.1 Establish Needs with Stakeholders
Activities:
- Define purpose and scope
- Manage expectations

OUTPUT
▪ Plan of Action and Milestones
▪ Stakeholder Consensus
▪ Cost Team Formation

1.2 Establish a Program Baseline
Activities:
- Review Cost Analysis Requirements Description (CARD) or CARD -like documents
- Identify cost drivers (e.g., speed, weight, SLOC)
- Identify risk areas

OUTPUT
▪ Technical Baseline
▪ Ground Rules
▪ Risk Areas

Re-visit — Initial Review — Proceed

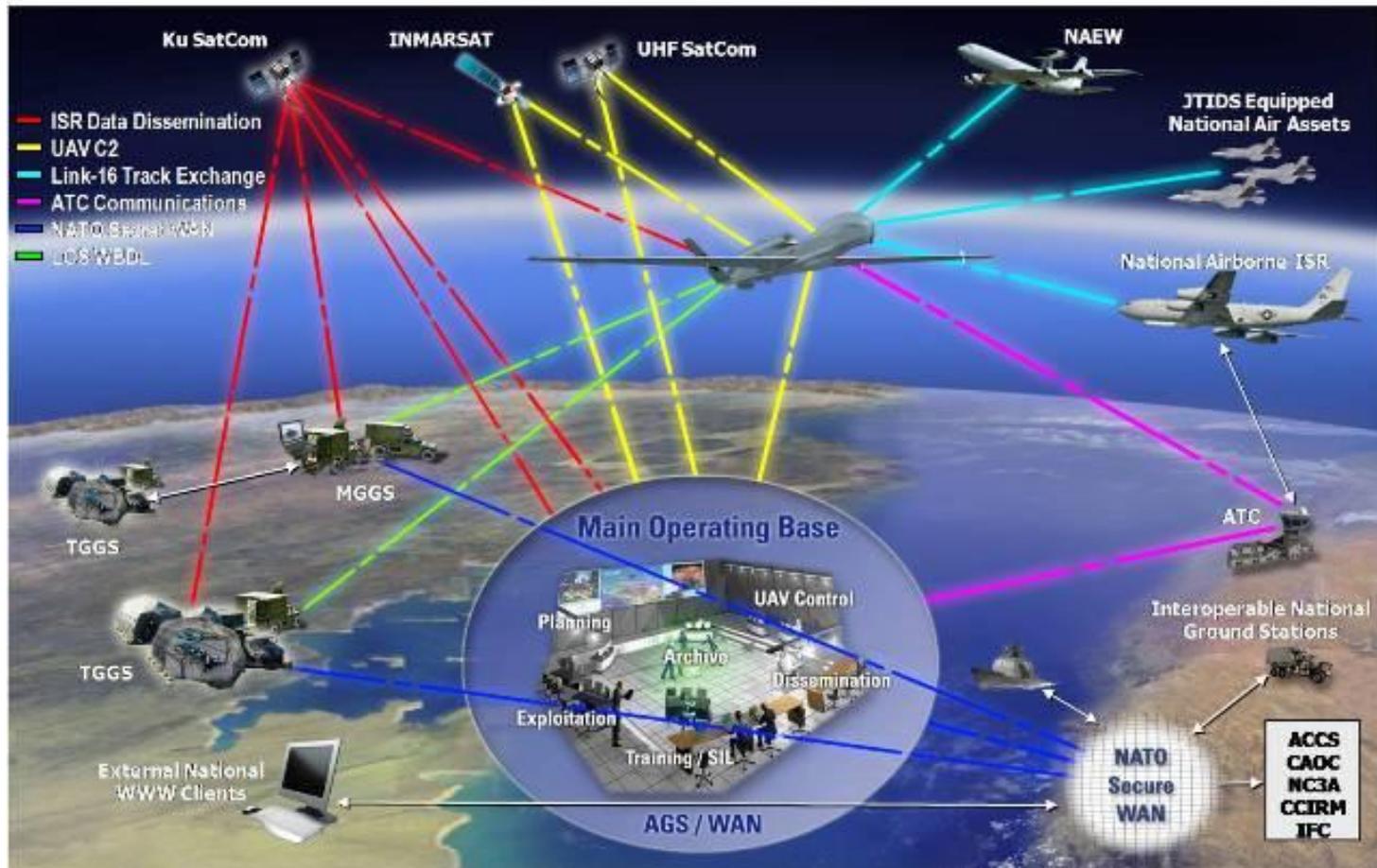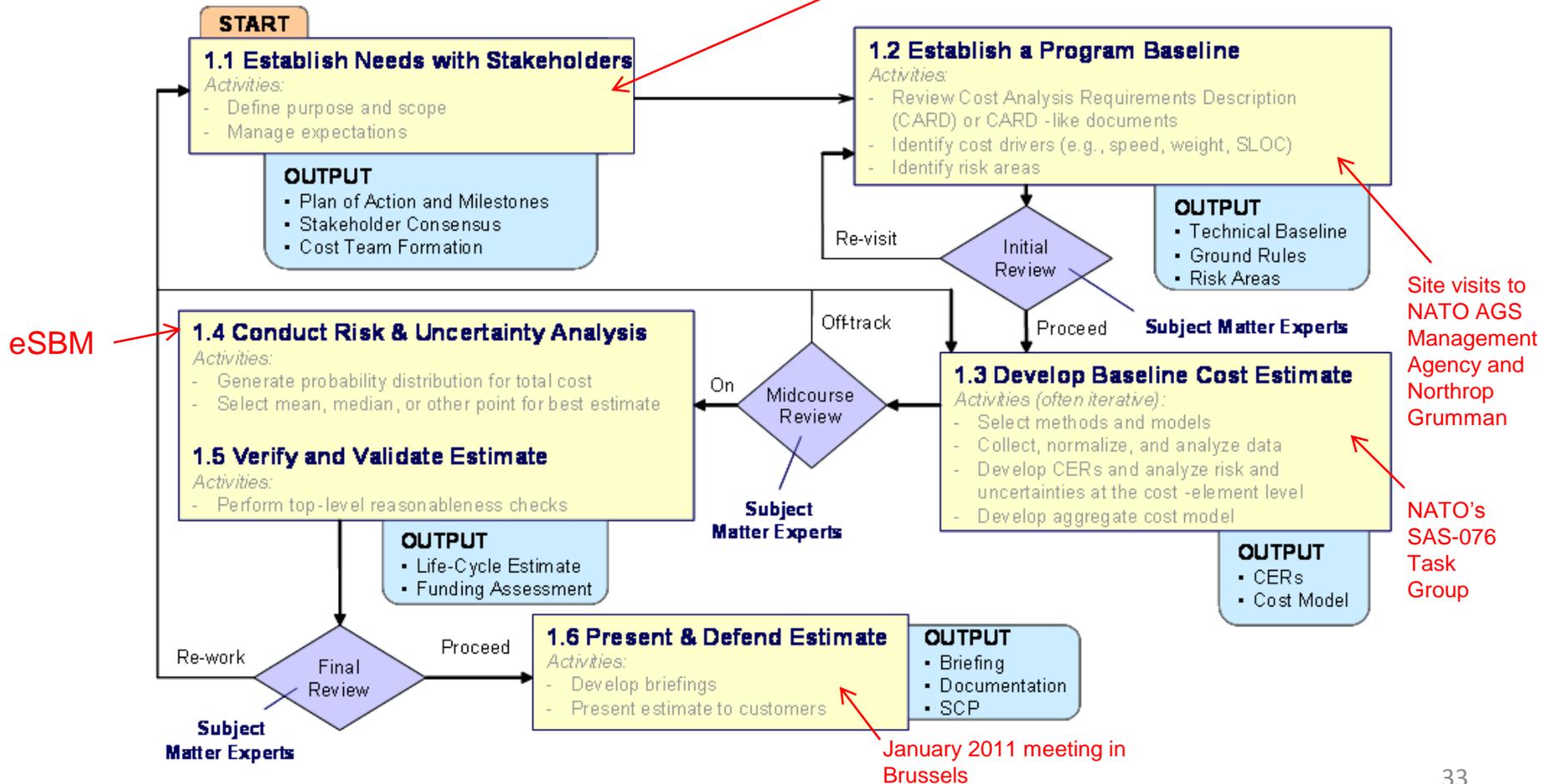**Subject Matter Experts**

Site visits to NATO AGS Management Agency and Northrop Grumman

1.4 Conduct Risk & Uncertainty Analysis
Activities:
- Generate probability distribution for total cost
- Select mean, median, or other point for best estimate

1.5 Verify and Validate Estimate
Activities:
- Perform top-level reasonableness checks

OUTPUT
▪ Life-Cycle Estimate
▪ Funding Assessment

Off-track

On — Midcourse Review

Subject Matter Experts

1.3 Develop Baseline Cost Estimate
Activities (often iterative):
- Select methods and models
- Collect, normalize, and analyze data
- Develop CERs and analyze risk and uncertainties at the cost -element level
- Develop aggregate cost model

OUTPUT
▪ CERs
▪ Cost Model

NATO's SAS-076 Task Group

Re-work — Final Review — Proceed

Subject Matter Experts

1.6 Present & Defend Estimate
Activities:
- Develop briefings
- Present estimate to customers

OUTPUT
▪ Briefing
▪ Documentation
▪ SCP

January 2011 meeting in Brussels

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

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

Notional Quantity Profile

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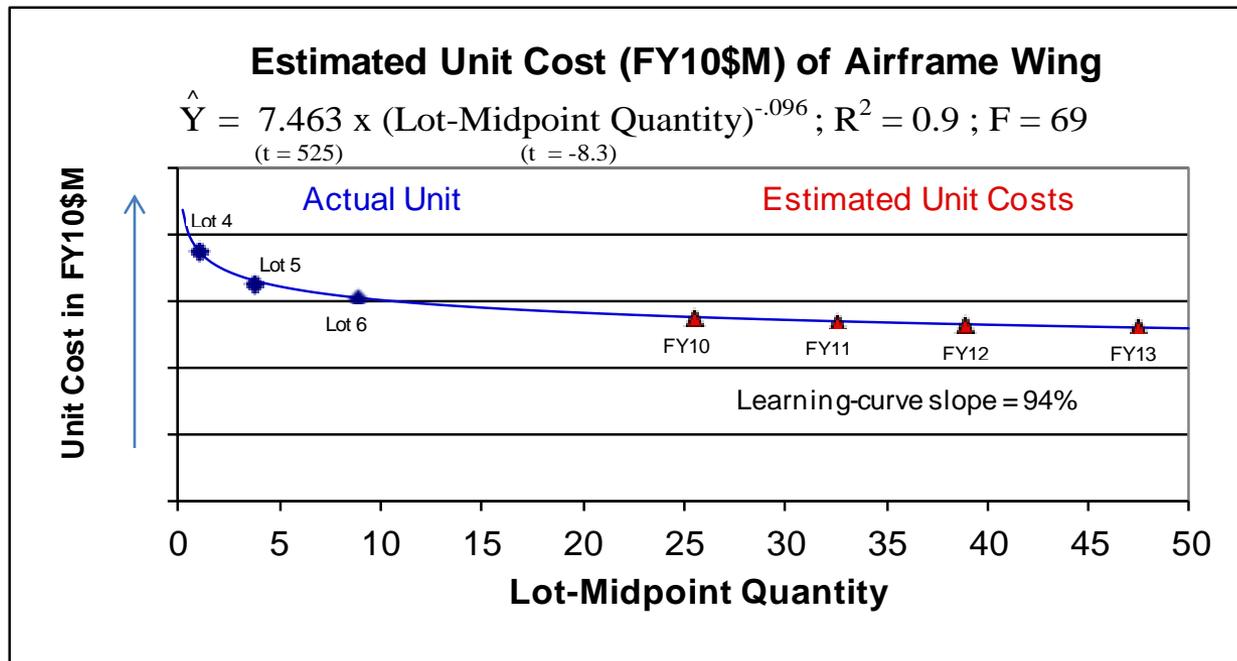 - BAMS development and production

Cumulative Block 30 & 40 Air Vehicles

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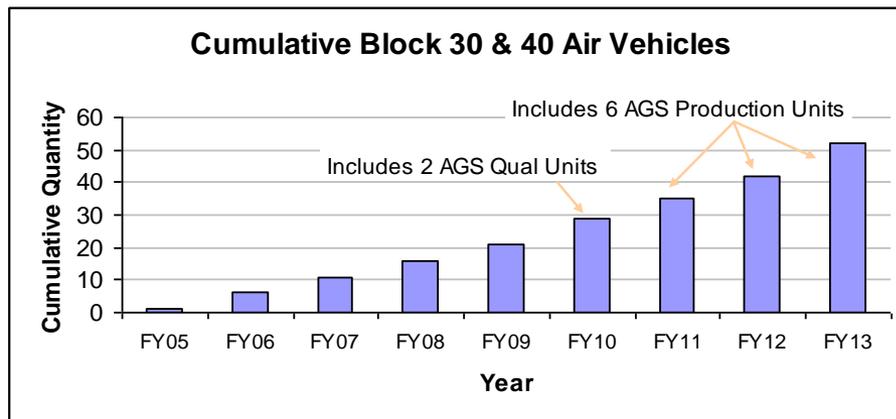
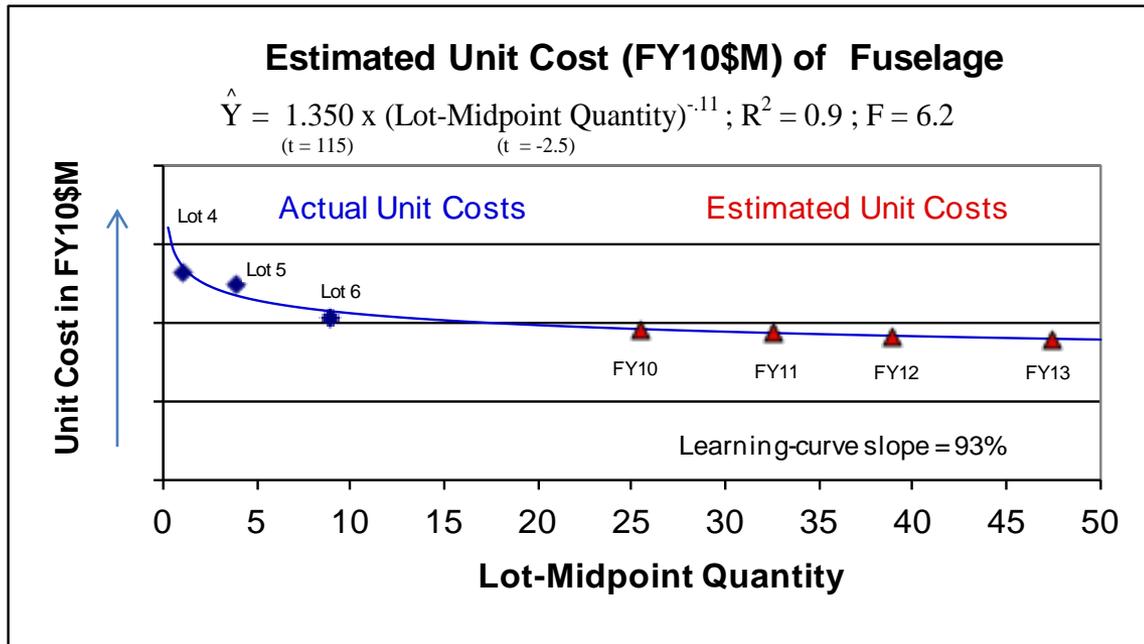| Buy Year; TOA Funding	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
U.S. Global Hawk LRIP	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9	Lot 10	Lot 11	Lot 12
Block 10 Aircraft	3	3	1									
Block 20 Aircraft			3	3								
Block 30 Aircraft				1	4	5	2	2	2	2	3	3
Block 40 Aircraft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

Example: Airframe Wing

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

Estimated Unit Cost (FY10$M) of Airframe Wing

$$\hat{Y} = 7.463 \text{ x (Lot-Midpoint Quantity)}^{-.096} ; R^2 = 0.9 ; F = 69$$

(t = 525) (t = -8.3)

Actual Unit   Estimated Unit Costs

Lot 4
Lot 5
Lot 6
FY10   FY11   FY12   FY13

Learning-curve slope = 94%

Unit Cost in FY10$M

0   5   10   15   20   25   30   35   40   45   50

Lot-Midpoint Quantity

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

Estimated Unit Cost (FY10$M) of Fuselage

$$\hat{Y} = 1.350 \times (\text{Lot-Midpoint Quantity})^{-.11}\ ;\ R^2 = 0.9\ ;\ F = 6.2$$

(t = 115)   (t = -2.5)

Actual Unit Costs   Estimated Unit Costs

Lot 4

Lot 5

Lot 6

FY10   FY11   FY12   FY13

Learning-curve slope = 93%

Unit Cost in FY10$M

Lot-Midpoint Quantity

0   5   10   15   20   25   30   35   40   45   50

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
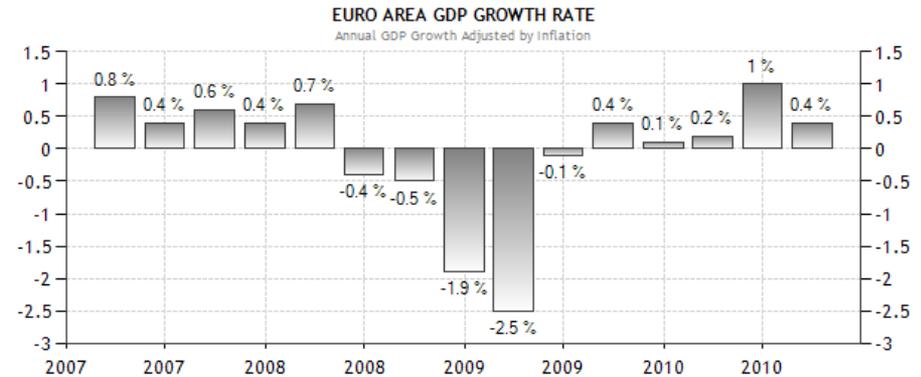
Exchange Rate

"Random Walk" Theory

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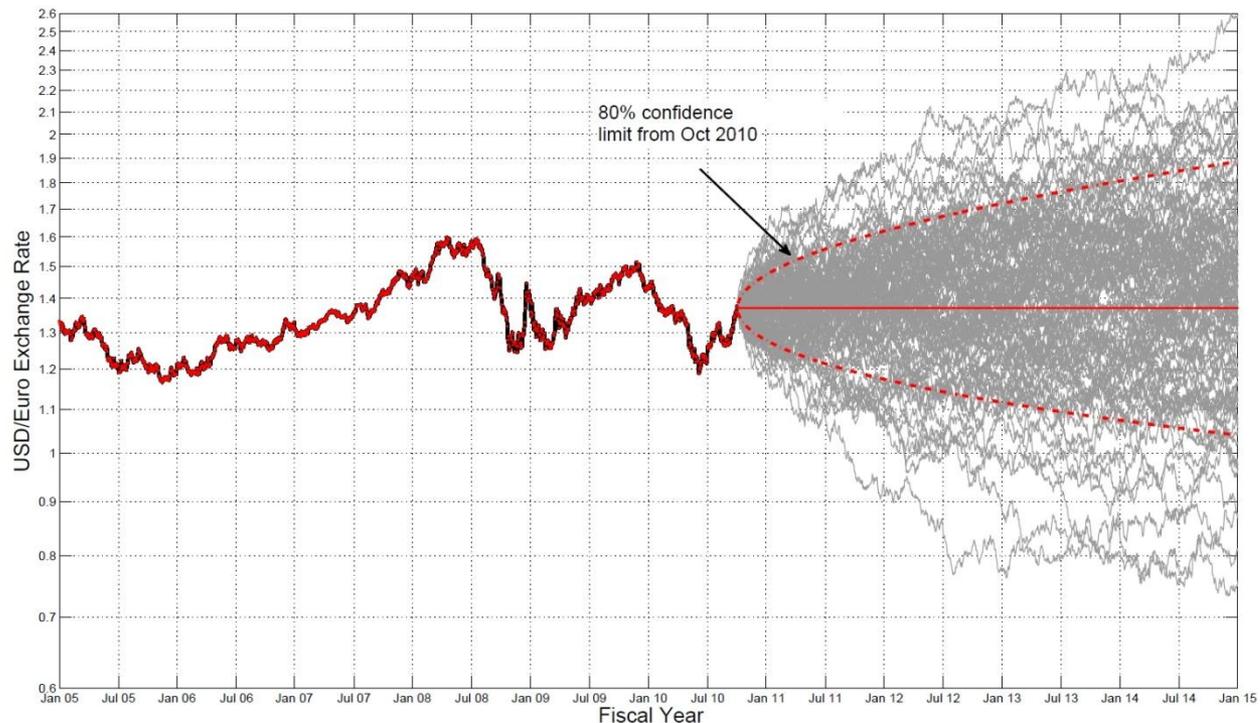
Inflation Rate

Threat of Rising Rates

- 3.0 %/yr as baseline

- Economic recovery gaining traction
  - North America and Europe
  - Inflation in Euro zone at two-year high of 2.2% (above 2.0% ECB target)
    - Food, energy, raw materials
    - Risk of second-round effect on wages
  - Aerospace inflation higher than in general economy

EURO AREA GDP GROWTH RATE
Annual GDP Growth Adjusted by Inflation

EURO AREA INFLATION RATE
Annual Change on Consumer Price Index

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

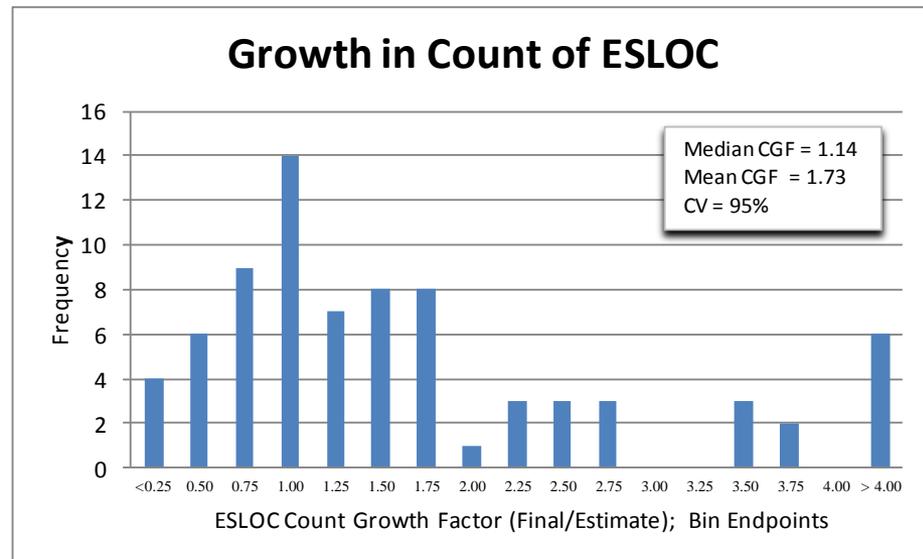- Schedule delays increase costs in then-year US$, Canadian$, and Euros

Bulgaria, Canada, 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)

Growth in Count of ESLOC

Median CGF = 1.14
Mean CGF = 1.73
CV = 95%

ESLOC Count Growth Factor (Final/Estimate); Bin Endpoints

"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
    - 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

Prime	2nd Level Subs	Country	
NGISSII USA	Northrop Grumman Systems Corp (NGSC)	USA	
	CASSIDIAN (EADS) Potential subs to Cassidian: Retia ICZ (Czech Republic); Aktors (Estonia); Dati (Latvia); Elsis (Lithuania); Konstrukta (Slovakia); Hermes Soft Lab (Slovenia)	Germany	
	Selex Galileo	Italy	
	General Dynamics Canada	Canada	
	Kongsberg	Norway	

3rd Level Subs Nations	
Bulgaria	
Czech Republic	
~~Denmark~~	
Estonia	
Latvia	
Lithuania	
Luxemburg	
Romania	
Slovakia	
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)
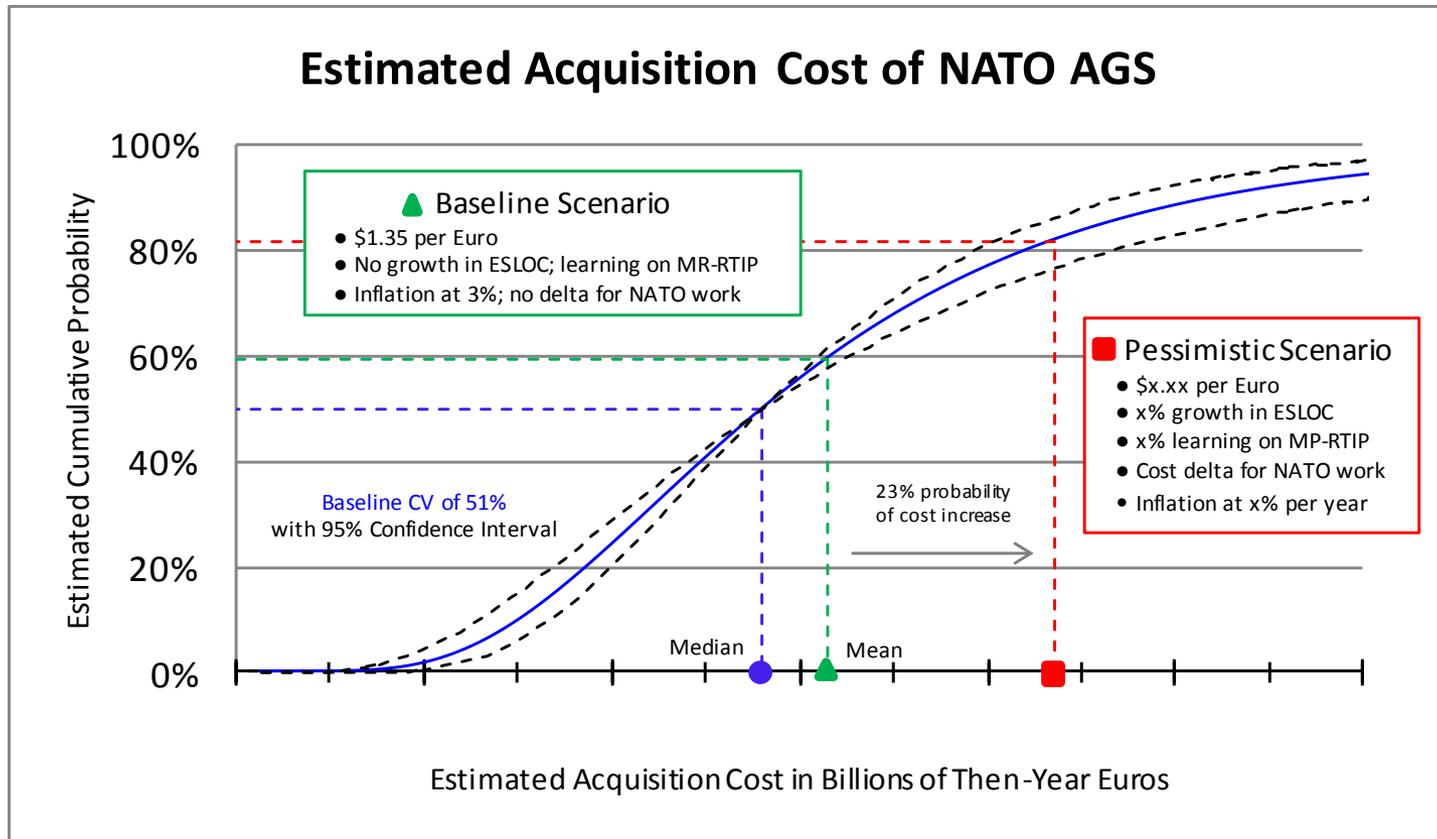   - Based on complete sample at MS B

Scenarios

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

Scenario Parameters

Elements	Baseline					Pessimistic					Constrained				
Exchange rate	$1.35 per €					$x.xx per €					$x.xx per €				
Inflation rate	3.00%					x%					x%				
						slip in schedule									
Quantities/Schedule	FY11	FY12	FY13	FY14	FY15	FY11	FY12	FY13	FY14	FY15	FY11	FY12	FY13	FY14	FY15
UAVs	2	2	2	2	0										
Ground Stations											change in quantities and schedule				
Transportable	1	1	1	1	0										
Mobile	2	3	3	3	0										
ESLOC Count	No growth					x% increase					No growth				
Radar	91% learning					x% learning					91% learning				
Int'l Participation	Built-in redundancy					x% delta to SE/PM					Built-in redundancy				
Affordability	Unconstrained					Unconstrained					Constrained				

S-Curve for NATO AGS

Estimated Acquisition Cost of NATO AGS

Estimated Cumulative Probability

▲ Baseline Scenario
- $1.35 per Euro
- No growth in ESLOC; learning on MR-RTIP
- Inflation at 3%; no delta for NATO work

■ Pessimistic Scenario
- $x.xx per Euro
- x% growth in ESLOC
- x% learning on MP-RTIP
- Cost delta for NATO work
- Inflation at x% per year

Baseline CV of 51%
with 95% Confidence Interval

23% probability
of cost increase

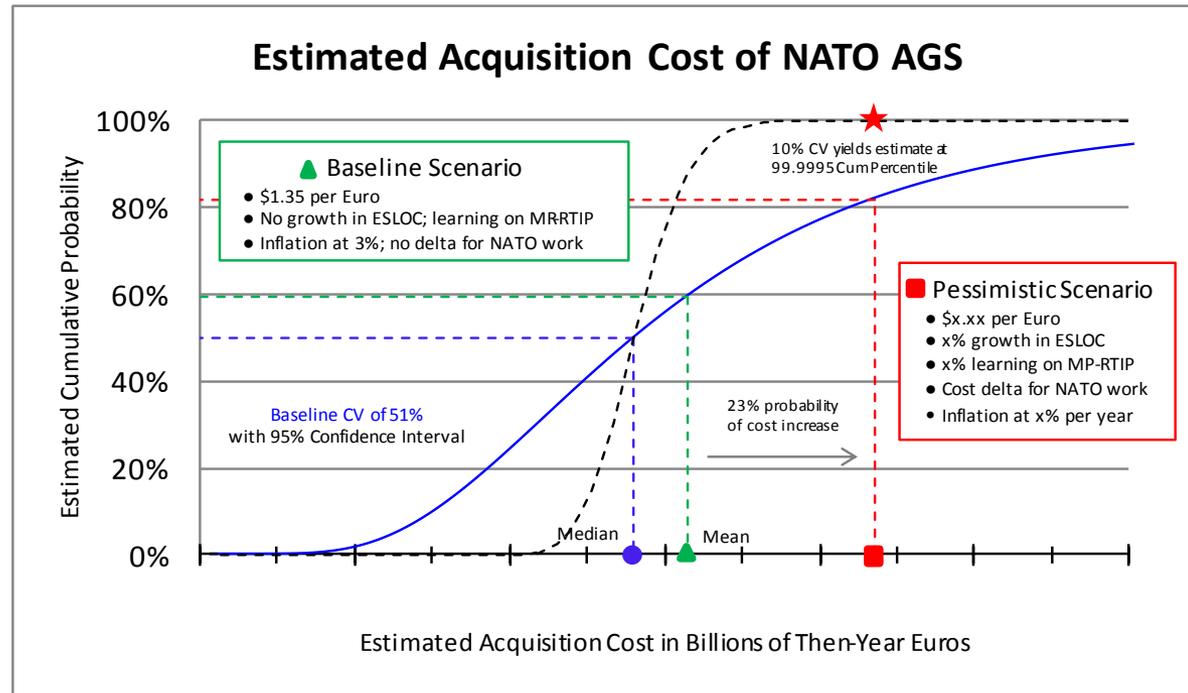Median   Mean

Estimated Acquisition Cost in Billions of Then-Year Euros

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"

Estimated Acquisition Cost of NATO AGS

Estimated Cumulative Probability

100%
80%
60%
40%
20%
0%

▲ Baseline Scenario
- $1.35 per Euro
- No growth in ESLOC; learning on MRRTIP
- Inflation at 3%; no delta for NATO work

10% CV yields estimate at 99.9995 Cum Percentile

■ Pessimistic Scenario
- $x.xx per Euro
- x% growth in ESLOC
- x% learning on MP-RTIP
- Cost delta for NATO work
- Inflation at x% per year

Baseline CV of 51%
with 95% Confidence Interval

23% probability of cost increase

Median   Mean

Estimated Acquisition Cost in Billions of Then-Year Euros

Cost values not displayed because of business sensitivity

49

S-Curve Tool

- Excel based
  - Reflects historical CVs and Cost Growth Factors (CGFs)
  - Supports both
    - Monte Carlo simulation
    - eSBM
- 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
- 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,
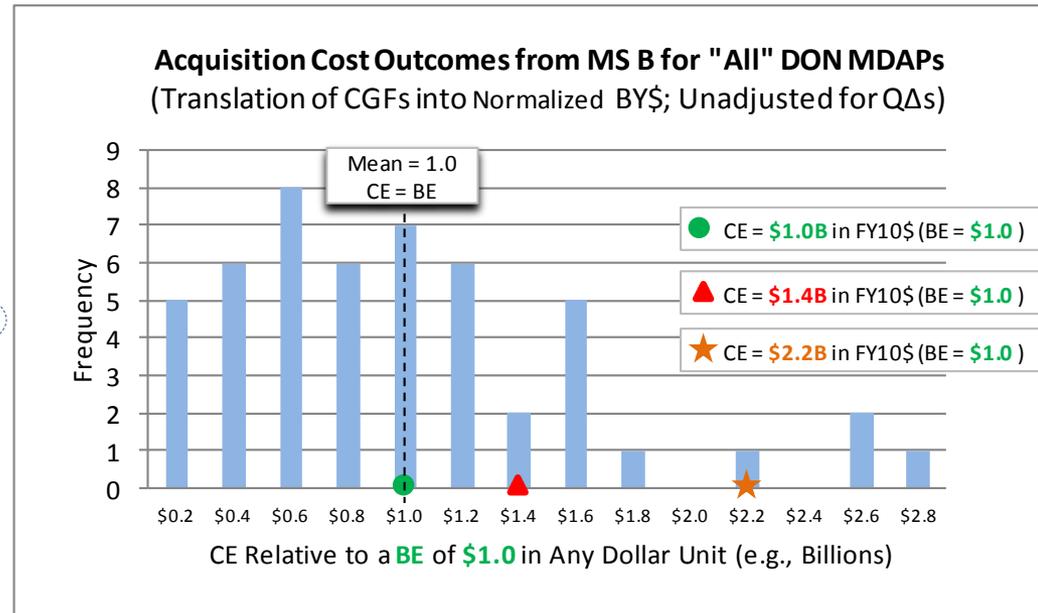Jack Smuck, Megan Guild, and Richard L. Coleman;
SCEA/ISPA Conference 2011

Translation of BY$ CGFs Into Costs

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

Steps:

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

- 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

Acquisition Cost Outcomes from MS B for "All" DON MDAPs
(Translation of CGFs into Normalized BY$; Unadjusted for QΔs)

Mean = 1.0
CE = BE

CE = **$1.0B** in FY10$ (BE = **$1.0**)
CE = **$1.4B** in FY10$ (BE = **$1.0**)
CE = **$2.2B** in FY10$ (BE = **$1.0**)

Frequency

$0.2 $0.4 $0.6 $0.8 $1.0 $1.2 $1.4 $1.6 $1.8 $2.0 $2.2 $2.4 $2.6 $2.8

CE Relative to a BE of **$1.0** in Any Dollar Unit (e.g., Billions)

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

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Military Reading List

Nonfiction

- <u>With the Old Breed</u>, 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.

- <u>Unbroken</u>, 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.

- <u>Ambush Alley</u>, Tim Pritchard
  - According to many, "the most extraordinary battle of the Iraq war. "

- <u>Inside Delta Force</u>, Eric Haney
  - A gripping account of the formation, operation, and skills of America's elite counter-terrorism unit.

- <u>Horse Soldiers</u>, Doug Stanton
  - U.S. Special Forces defeat the Taliban in Afghanistan shortly after 9/11.

Fiction

- <u>Ender's Game</u>, 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.