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)**

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 $\Delta$
  – Then-year dollars
    ➢ $23.28B/$14.08B = 1.65
  – Base-year dollars
    ➢ $14.11B/$9.01B = 1.57

• Adjusted for quantity $\Delta$, 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

<table>
<thead>
<tr>
<th>SAR BE</th>
<th>Program Office's Acquisition Cost Estimate</th>
<th>ICE (CAIG for ID; NCCA for IC)</th>
<th>Ratio of POACE to SAR BE</th>
<th>Ratio of POACE to SAR BE</th>
<th>Ratio of ICE to SAR BE</th>
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<td>in TY$</td>
<td>in BY$</td>
<td>in TY$</td>
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<td>$31,548</td>
<td>$36,296</td>
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<td>$39,100</td>
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<tr>
<td>$2,977</td>
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<td>$3,284</td>
<td>$3,505</td>
<td><strong>1.01</strong></td>
<td>1.00</td>
</tr>
</tbody>
</table>

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**
  - Base Year $\quad$ Then Year $\quad$ Quantity
- **Baseline Estimate**
  - Base Year $\quad$ Then Year $\quad$ Quantity
- **Changes to Date**
  - Base Year $\quad$ Then Year $\quad$ Quantity
- **Current Estimate**
  - Base Year $\quad$ Then Year $\quad$ Quantity
- **Quantity Changes**
  - Base Year $\quad$ Then Year $\quad$
- **Date of last SAR**

**Sample Data at MS B**

- F/A-18 E/F
- JSOW
- Expeditionary Fighting Vehicle (formerly AAAV)
- MIDS - Low Volumne Terminal (LVT)
- Cooperative Engagement
- F-14D
- H-1 UPGRADES
- MH-60S
- TACTICAL TOMAHAWK
- MH-60R
- E-2D Advanced Hawkeye
- EA-18G (Electronic Attack)
- COBRA JUDY REPLACEMENT
- P-8A
- Mobile User Objective System (MOUS)
- SM-6
- AGM-88E AARGM

**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 |
|---|---|---|---|
| Statistics | (Without Qty Adjustment) | (Quantity Adjusted) |
| 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 |

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%
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

<table>
<thead>
<tr>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base-Year$</td>
<td>Then-Year$</td>
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<tr>
<td>Mean</td>
<td>1.78</td>
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<tr>
<td>Standard Deviation</td>
<td>0.95</td>
<td>1.38</td>
</tr>
<tr>
<td>CV</td>
<td>0.54</td>
<td>0.64</td>
</tr>
</tbody>
</table>

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%

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MS B: Ships and Submarines
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%)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
</tr>
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<tbody>
<tr>
<td>Base-Year$</td>
<td>Then-Year$</td>
<td>Base-Year$</td>
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<tr>
<td>Mean</td>
<td>1.55</td>
<td>2.03</td>
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<td>Standard Deviation</td>
<td>0.89</td>
<td>1.87</td>
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<tr>
<td>CV</td>
<td>0.57</td>
<td>0.92</td>
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</table>
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%)

<table>
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<tr>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
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<tr>
<td>Mean</td>
<td>1.44</td>
<td>1.94</td>
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<tr>
<td>Standard Deviation</td>
<td>1.19</td>
<td>1.93</td>
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<tr>
<td>CV</td>
<td>0.82</td>
<td>0.99</td>
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</table>

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%
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) |
| Mean                                          | 1.14 | 1.14 |
| Standard Deviation                            | 0.67 | 0.69 |
| CV                                            | 0.59 | 0.61 |

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%
Hypothesis Testing for MS B

Hypothesis

- Homogeneity of CGF means
  - $H_0$: $\mu_1 = \mu_2 = \ldots = \mu_k$, where $\mu_i$ 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](image)
Hypothesis Testing for MS B

Hypothesis

• Homogeneity of CGF variances
  
  ▪ $H_0: \sigma^2_1 = \sigma^2_2 = \ldots = \sigma^2_k$, where $\sigma^2_i$ 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

Test Results

• Pairwise comparisons
  
  – In all cases, $H_0$ 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; $H_0$ 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

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 Cushion |
| LSD-41 Landing Ship Dock |
| LSD-49 Landing Ship Dock |
| MCM-1 Mine Counter |
| TAO-187 Fleet Oiler |
| Trident II Submarines |
| CVN-76 |
| MHC-51 Mine Hunter |
| T-AGOS |
| CVN-68 Class (two ships) |
| CVN-68 Class (one ship) |
| Battleship Reactivation |
| SSN-21 & AN/BSY-2 |
| A-6E/F |
| AN/SQQ-89 Anti-Submarine |
| E-2C |
| EA-6B |
| F-14D |
| MK-48 ADCAP |
| P-3C |
| PHALANX CIWS |
| T-45TS |
| TRIDENT II MISSILE |
| V-22 |
| UHF FOLLOW-ON |
| ROTH (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**

<table>
<thead>
<tr>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base-Year$</td>
<td>Then-Year$</td>
</tr>
<tr>
<td>Mean</td>
<td>1.11</td>
<td>1.08</td>
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<tr>
<td>Standard Deviation</td>
<td>0.50</td>
<td>0.58</td>
</tr>
<tr>
<td>CV</td>
<td>0.45</td>
<td>0.53</td>
</tr>
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</table>

**CVs for Total Acquisition Cost: MS B and MS C**

- CVs from MS B: 0.87, 0.63, 0.51, 0.36
- CVs from MS C: 0.53, 0.45, 0.26, 0.19

**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%
Comparison with “All DON”

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

<table>
<thead>
<tr>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
</tr>
</thead>
<tbody>
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<td>Base-Year$</td>
<td>Then-Year$</td>
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<tr>
<td>Mean</td>
<td>1.15</td>
<td>1.12</td>
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<tr>
<td>Standard Deviation</td>
<td>0.59</td>
<td>0.74</td>
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<td>CV</td>
<td>0.52</td>
<td>0.66</td>
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**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%
**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%)

---

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Base-Year$</th>
<th>Then-Year$</th>
<th>Base-Year$</th>
<th>Then-Year$</th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td>1.17</td>
<td>1.08</td>
<td>1.15</td>
<td>1.12</td>
</tr>
<tr>
<td>Standard Deviation</td>
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<tr>
<td>CV</td>
<td>0.38</td>
<td>0.36</td>
<td>0.27</td>
<td>0.36</td>
</tr>
</tbody>
</table>

---

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

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

Insufficient sample sizes for missiles and electronics

MS C: “Other”

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

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

Cost Growth Factors & CVs for "Other" MDAPs at MS C; n = 11

<table>
<thead>
<tr>
<th></th>
<th>Statistics</th>
<th>(Without Qty Adjustment)</th>
<th>(Quantity Adjusted)</th>
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<td>Base-Year$</td>
<td>Then-Year$</td>
<td>Base-Year$</td>
</tr>
<tr>
<td>Mean</td>
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<td>1.00</td>
<td>1.07</td>
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<tr>
<td>Standard Deviation</td>
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<td>0.45</td>
<td>0.16</td>
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<tr>
<td>CV</td>
<td>0.40</td>
<td>0.45</td>
<td>0.15</td>
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Sample Median 
and Mean

ROTMR
Navy EHF Satellite

Trident II Missile
Tactical Tomahawk

AN/SQQ-89
MK-48 ADCAP
PHALANX CIWS
UHF Follow-On

JSOW Baseline/Unitary
MIDS
Cooperative Engagement Capability

< 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

Cost Growth Factor (Current Estimate/Baseline Estimate)
Hypothesis Testing for MS C

Hypothesis

• Homogeneity of CGF means
  • $H_0$: $\mu_1 = \mu_2 = \ldots = \mu_k$, where $\mu_i$ 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$)

<table>
<thead>
<tr>
<th>Category</th>
<th>Sample $\sigma^2$</th>
<th>Sample $\sigma^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ships &amp; Subs</td>
<td>0.06</td>
<td>1.07</td>
</tr>
<tr>
<td>Aircraft</td>
<td>0.16</td>
<td>1.12</td>
</tr>
<tr>
<td>Other</td>
<td>0.03</td>
<td>1.12</td>
</tr>
</tbody>
</table>
Hypothesis Testing for MS C

Hypothesis

- Homogeneity of CGF variances
  - \( H_0: \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_k^2 \) where \( \sigma_i \) is a platform population variance CGF
  - \( H_a: \sigma_i^2 \neq \sigma_j^2 \), for at least one \((i,j)\) pair

- Statistical tests:
  - Pairwise comparisons
  - Levene test for \( k \) samples

Test Results

- Mixed
  - Pairwise comparisons
    - \( H_0 \) 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; \( H_0 \) not rejected
  - On balance, deltas in sample variances not distinguishable from noise

<table>
<thead>
<tr>
<th>Sample Pairwise F Statistics</th>
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<tbody>
<tr>
<td>Platforms</td>
</tr>
<tr>
<td>Ships and Subs</td>
</tr>
<tr>
<td>Aircraft</td>
</tr>
<tr>
<td>Other</td>
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</tbody>
</table>

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]

- Quantity Unadjusted
- Quantity Adjusted

- 1978 (1 datum) & => 1980s; n = 43
- => 1990; n = 20

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

• 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)

Estimated from historical data
Estimated by analogy

<table>
<thead>
<tr>
<th>Coefficient of Variation</th>
<th>MS A</th>
<th>MS B</th>
<th>MS C</th>
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<tbody>
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<td>0.42</td>
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<td>0.51</td>
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<tr>
<td>0.66</td>
<td>0.21</td>
<td>0.34</td>
<td>0.21</td>
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</table>
Case Study #1

NATO Alliance Ground Surveillance System
NATO AGS Program
ICE Methodology

Based on DON Cost Estimating Guide

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

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

1.4 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

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

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

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

OUTPUT
- Briefing
- Documentation
- SCP

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

Site visits to NATO AGS Management Agency and Northrop Grumman

NATO’s SAS-076 Task Group

January 2011 meeting in Brussels
Cost Element Structure

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<thead>
<tr>
<th>Numeric Element</th>
<th>Cost Element</th>
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<td>NATO AGS UAV System</td>
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<td>Air Vehicle</td>
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<td>Airframe</td>
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<td>1.1.1.1</td>
<td>Wing</td>
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<td>Fuselage</td>
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<td>1.1.1.4</td>
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<td>OmniStar Differential Global Positioning System (DGPS)</td>
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<td>1.1.4.3</td>
<td>IFF Transponder/ Traffic Alert &amp; Collision (TCAS-II)</td>
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<tr>
<td>1.1.4.4</td>
<td>Worldwide Operations Hardware Suite</td>
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<td>1.1.5</td>
<td>Central Computer</td>
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<td>1.1.6</td>
<td>Auxiliary Equipment</td>
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<td>1.1.7</td>
<td>Integration, Assembly, Test &amp; Checkout</td>
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<td>1.2</td>
<td>Payloads</td>
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<td>Electronic Support Measures (ESM)</td>
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<td>Ground/Support Segment</td>
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<td>Common Support Equipment</td>
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<td>Operational / Site Activation</td>
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<td>Industrial Facilities</td>
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<td>Initial Spares and Repair Parts</td>
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<td>General and Administrative</td>
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<td>Facilities</td>
<td>Facilities Capital Cost of Money</td>
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<td>Profit</td>
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# ICE Methodology

## Unadjusted Point Estimate

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<th>Air Vehicle</th>
<th>Support Elements</th>
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<tr>
<td>– Global Hawk Block 30 and 40 actuals</td>
<td>– Global Hawk actuals</td>
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<tr>
<td>• Learning curves</td>
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<tr>
<td>• Averages</td>
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<td>Payload (MP RTIP)</td>
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<td>– Analogy to AESA</td>
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<td>Ground Segment</td>
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<td>– Analogies for hardware</td>
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<td>– CERs for software development</td>
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<tr>
<td>• Manmonths</td>
<td></td>
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<td>• Burdened salaries from Eurohawk</td>
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</table>
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](image)

<table>
<thead>
<tr>
<th>Buy Year; TOA Funding</th>
<th>FY02</th>
<th>FY03</th>
<th>FY04</th>
<th>FY05</th>
<th>FY06</th>
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<th>FY08</th>
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<th>FY11</th>
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<td>Design, Development, &amp; Qualification Production</td>
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</table>

Note: AGS scheduled 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

![Graph showing estimated unit cost (FY10$M) of airframe wing.](image)

Estimated Unit Cost (FY10$M) of Airframe Wing

\[
\hat{Y} = 7.463 \times (\text{Lot-Midpoint Quantity})^{-0.096} ; R^2 = 0.9 ; F = 69
\]

(t = 525) (t = -8.3)

Lot-Midpoint Quantity

Actual Unit

Estimated Unit Costs

Learning-curve slope = 94%
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

![Graph showing estimated and actual unit costs over different lots and fiscal years. The formula $\hat{Y} = 1.350 \times (\text{Lot-Midpoint Quantity})^{0.11}$ is given with $R^2 = 0.9$, $F = 6.2$, and the learning curve slope is 93%.](image-url)
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

- Software development
  - xx 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
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
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%

“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

<table>
<thead>
<tr>
<th>Prime</th>
<th>2nd Level Subs</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGISSII USA</td>
<td>Northrop Grumman Systems Corp (NGSC)</td>
<td>USA</td>
</tr>
<tr>
<td></td>
<td>CASSIDIAN (EADS)</td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td>Potential subs to Cassidian: Retia ICZ (Czech Republic); Aktors (Estonia); Dati (Latvia); Elsis (Lithuania); Konstrukta (Slovakia); Hermes Soft Lab (Slovenia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selex Galileo</td>
<td>Italy</td>
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<tr>
<td></td>
<td>General Dynamics Canada</td>
<td>Canada</td>
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<td></td>
<td>Kongsberg</td>
<td>Norway</td>
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<table>
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<tr>
<th>3rd Level Subs Nations</th>
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<tr>
<td>Bulgaria</td>
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<td>Estonia</td>
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</tr>
<tr>
<td>Slovakia</td>
</tr>
<tr>
<td>Slovenia</td>
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</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Elements</th>
<th>Baseline</th>
<th>Pessimistic</th>
<th>Constrained</th>
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<tbody>
<tr>
<td>Exchange rate</td>
<td>$1.35 per €</td>
<td>$x.xx per €</td>
<td>$x.xx per €</td>
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<td>Inflation rate</td>
<td>3.00%</td>
<td>x%</td>
<td>x%</td>
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<td>Quantities/Schedule</td>
<td>FY11 FY12 FY13 FY14 FY15</td>
<td>slip in schedule</td>
<td>change in quantities and schedule</td>
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<td>UAVs</td>
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<tr>
<td>Ground Stations</td>
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<td>Transportable</td>
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<tr>
<td>Mobile</td>
<td>2 2 2 2 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESLOC Count</td>
<td>No growth</td>
<td>x% increase</td>
<td>No growth</td>
</tr>
<tr>
<td>Radar</td>
<td>91% learning</td>
<td>x% learning</td>
<td>91% learning</td>
</tr>
<tr>
<td>Int'l Participation</td>
<td>Built-in redundancy</td>
<td>x% delta to SE/PM</td>
<td>Built-in redundancy</td>
</tr>
<tr>
<td>Affordability</td>
<td>Unconstrained</td>
<td>Unconstrained</td>
<td>Constrained</td>
</tr>
</tbody>
</table>
S-Curve for NATO AGS

Estimated Acquisition Cost of NATO AGS

- **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

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

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 MR-RTIP
- Cost delta for NATO work
- Inflation at x% per year

23% probability of cost increase

10% CV yields estimate at 99.9995 Cum Percentile

Cost values not displayed because of business sensitivity
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 unrepeateable 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: \( \text{CE/BE}_{1,1984}, \text{CE/BE}_{2,1978}, \text{CE/BE}_{3,1986}, \ldots, \text{CE/BE}_{50,2004} \)

where \( i,j = \) observation number, base year of numerator and denominator

Steps:

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

– Normalize CGFs to mean of 1.0  
  • \( \text{CE} = \text{BE} \) at the mean

– Each \( \text{CE} \) now interpretable as a cost outcome per dollar of \( \text{BE} \)  
  • Same units of measurement  
  • Same year dollars

– CV is unchanged  
  • Computation also holds for BY$ quantity adjustments

Desirable Statistical Properties:  
CV independent of base year  
CV independent of unit of measurement

Questionable Statistical Property:  
CV invariant with respect to program size

CV of costs & CGFs = 63%
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.