



Estimating Missile Guidance & Control Development Engineering (DE) Cost: An Important Advance

Speaking Today



Olivia Collins
Lead Analyst

Olivia Collins is a Lead Analyst at Technomics, Inc. with three years cost analysis experience. Currently she supports the Air Force Cost Analysis Agency (AFCAA) Non-ACAT I cost and software data reporting (CSDR) collection efforts. She also collects, organizes, and normalizes cost data for the Office of the Deputy Assistant Secretary of the Army for Cost and Economics (ODASA-CE). Olivia is working towards her MS in Data Analytics Engineering at George Mason University.



James York
Subject Matter Expert

Mr. York has over 40 years' experience in DOD system cost analysis and system acquisition. Primary experience is with aircraft, missile, avionics and electronics systems, particularly advanced technology sensors, processors, airframes and propulsion, including acquisition and O&S phase. Experience includes cost data base development, statistical CER development, cost model and cost estimate development, cost-risk, and cost-effectiveness analysis, as well as development of independent government estimates for source selections, contract negotiations and evaluation of cost proposals.

Outline

- Research Objective
- Ground Rules
- Cost Dataset
- Technical Dataset
- Data Assessment
- CER Development
- Conclusions

Preface

- Tables and Figures edited or formatted to obscure FOUO or contractor proprietary data.
- System names, scales on graphs are removed.
- Some cost and technical values on tables have been obscured or removed.

Research Objective

New estimating methodology for Tactical Missile Guidance & Control (G&C) Development Engineering (DE)

- An alternative to cost-to-cost factors (e.g., where DE cost is a factor of prototype mfg. or recurring cost)
 - Errors for cost factors are in the 50%-100%+ range
- A parametric relationship where DE cost is a function of one or more independent variables
 - Applicable to **EMD** programs

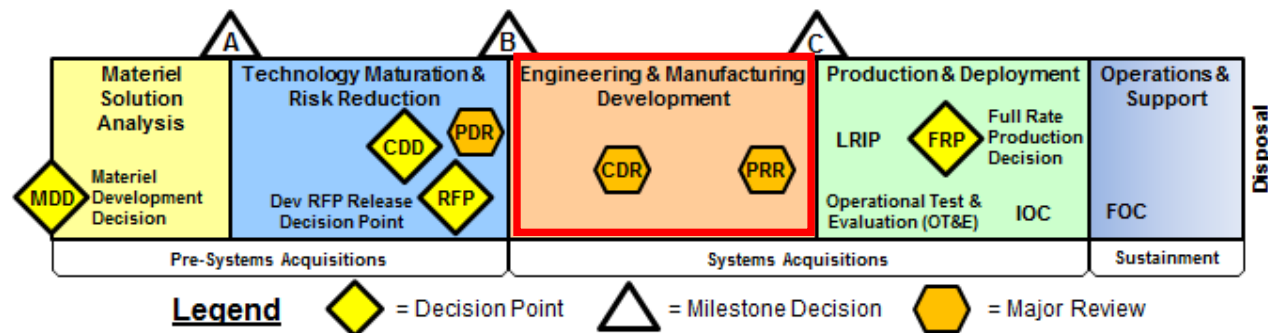


Image Source: AcqNotes

Ground Rules

DE cost = sum of several functional cost elements in Contractor Cost Data Report (CCDR) Form 1921-1, i.e.,

- Non-recurring Engineering (Labor, Material, OH), excluding G&A and Fee +
- Portion of Non-recurring Material that can be identified as DE, i.e.,
 - Non-rec Purchased Equipment (PE) and Non-rec “Other” (often used for subcontracts)

DD Form 1921-1 Functional Cost-Hour Report

FUNCTIONAL DATA ELEMENTS		COSTS AND HOURS INCURRED TO DATE			COSTS AND HOURS INCURRED AT COMPLETION		
		A. NONRECURRING	B. RECURRING	C. TOTAL	D. NONRECURRING	E. RECURRING	F. TOTAL
ENGINEERING							
(1) DIRECT ENGINEERING LABOR HOURS							
(2) DIRECT ENGINEERING LABOR DOLLARS							
(3) ENGINEERING OVERHEAD DOLLARS							
(4) TOTAL ENGINEERING DOLLARS							
MANUFACTURING OPERATIONS							
(5) DIRECT TOOLING LABOR HOURS							
(6) DIRECT TOOLING LABOR DOLLARS							
(7) DIRECT TOOLING & EQUIPMENT DOLLARS							
(8) DIRECT QUALITY CONTROL LABOR HOURS							
(9) DIRECT QUALITY CONTROL LABOR DOLLARS							
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(11) DIRECT MANUFACTURING LABOR DOLLARS							
(12) MANUFACTURING OPERATIONS OVERHEAD DOLLARS (Including Tooling and Quality Control)							
(13) TOTAL MANUFACTURING OPERATIONS DOLLARS (Sum of rows 6, 7, 9, 11, and 12)							
MATERIALS							
(14) RAW MATERIAL DOLLARS							
(15) PURCHASED PARTS DOLLARS							
(16) PURCHASED EQUIPMENT DOLLARS							
(17) MATERIAL HANDLING/OVERHEAD DOLLARS							
(18) TOTAL DIRECT-REPORTING SUBCONTRACTOR DOLLARS							
(19) TOTAL MATERIAL DOLLARS							
OTHER COSTS							
(20) OTHER COSTS NOT SHOWN ELSEWHERE (Specify in Remarks)							
SUMMARY							
(21) TOTAL COST (Direct and Overhead)							
22. REMARKS							

Non-rec Labor \$

Non-rec PE \$

Non-rec Other \$

Avoid using OLS which “favors” large observation values

- Used an iterative optimization model to minimize percent error
- Used multiple error metrics (i.e., median & mean absolute % error) to assess CER hypotheses

Cost Data Set – Selection Criteria

- Data for 38 total system variants (represents 22 programs) were reviewed
- Selection criteria
 - Must have Functional Cost-Hour Reporting (e.g., DD1921-1) or similar reports
 - Must have actual production cost history to develop Unit 1000 cost
 - Variants that were a modification of an original development G&C did not have Unit 1000 production cost history for only the modified G&C hardware – and these were excluded
 - Several programs had variants that were original, “all-up”, new G&C development program – they are included
 - This constrains and simplifies the analysis; but also means reliance on “older” data

Cost Data Set – Final Selection

System	Mission	Guidance Type
1	Air-to-air	Radio frequency (RF)
2	Strike	INS/GPS
3	Precision artillery	Electro-optic (EO)
4	Strike	INS/GPS
5	Anti-ship	RF
6	Defense suppression	RF
7	Anti-armor	EO
8	Strike	RF
9	Strike	INS/GPS; IR
10	Anti-tank, anti-armor	Infrared (IR)
11	Strike	INS/GPS
12	Strike	EO
13	Strike	IR
14	Air-defense	RF
15	Air-defense	RF
16	Air-to-air	IR
17	Air-defense	IR

- Filtered programs for data sufficiency and for variants
- Selected 17 (of 38) total system variants
 - 7 variants excluded due to lack of sufficient data
 - 14 variants excluded as evolutionary variants
- Data set has good variety of:
 - G&C missions
 - Guidance types
 - Target types
 - Launch types

Cost Data Set – Challenges

System	G&C Cost	LRIP G&C N-R Design Engr.
1	Guidance only	No N-R
2	G&C separate	Med N-R
3	G&C separate	No N-R
4	G&C combined	Small N-R
5	G&C separate	Large N-R
6	G&C separate	Small N-R
7	G&C combined	No N-R
8	Guidance only	Med N-R
9	G&C separate	Large N-R
10	G&C separate	No N-R
11	G&C separate	No N-R
12	G&C separate	No N-R
13	G&C separate	Large N-R
14	G&C combined	No N-R
15	G&C separate	Large N-R
16	Guidance only	No N-R
17	Guidance only	No N-R

Several Data Challenges Encountered

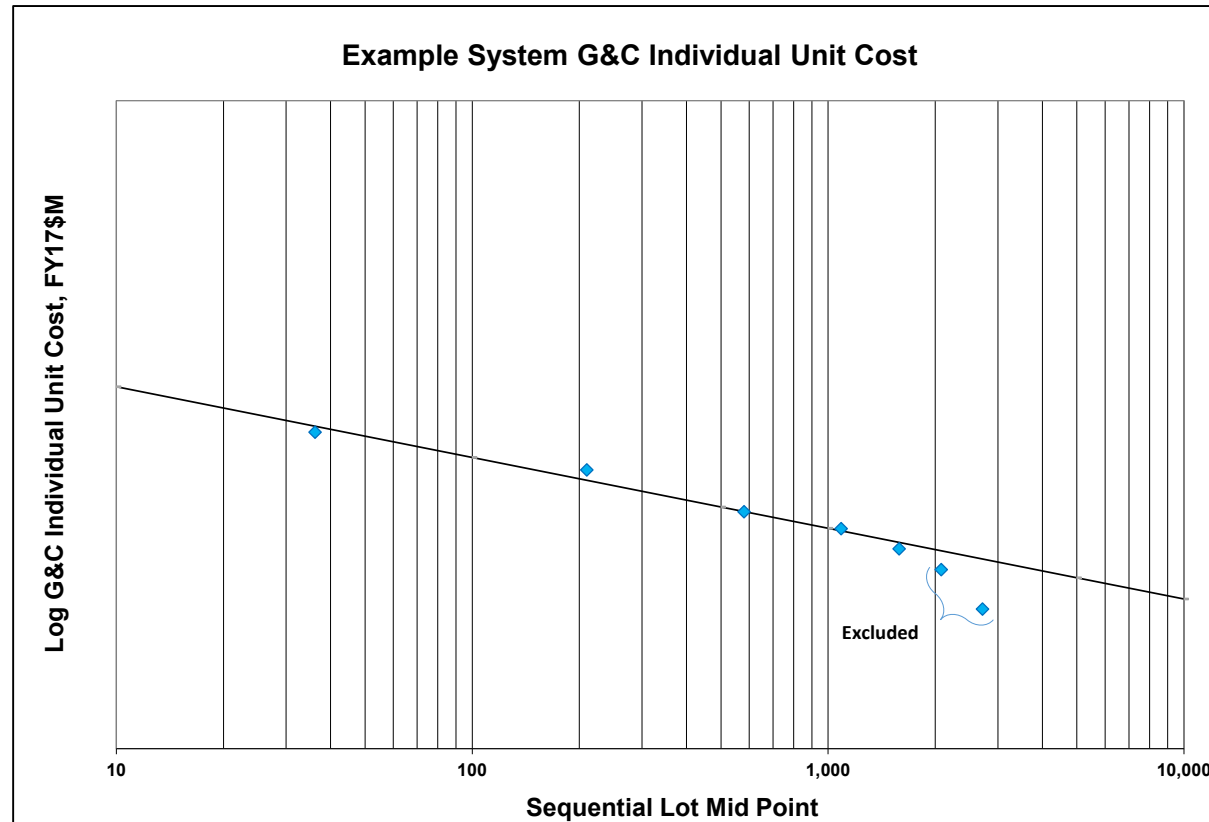
- When Control cost was unavailable – it was estimated, or Guidance only info was used
- Some systems clearly had DE cost reported in early production
 - Ground-rule to include non-recurring engineering cost from pilot production or LRIP
- Ensure G&C cost was consistent with MILSTD-881

Small:	< 5%
Medium:	5 – 10%
Large:	> 10%

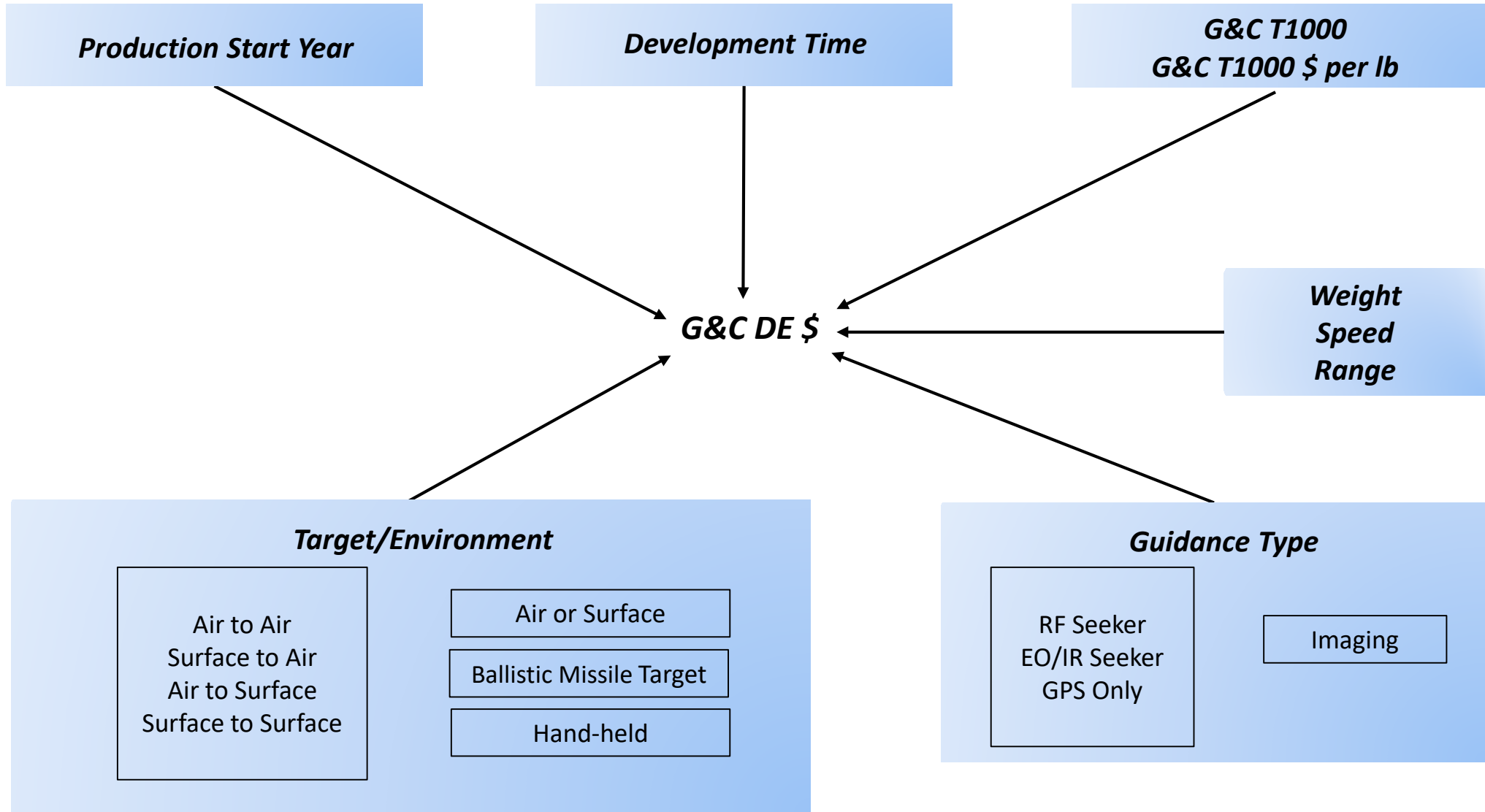
Can't take data at face value!

Cost Data Set – T1000 Normalization

- G&C T1000 definition
 - 1000th unit cost on a non-rate adjusted learning curve that best predicts the actual T1000 cost value
 - Excludes G&A and Fee
- Analyzed CCDR G&C cost data to develop G&C Learning Curves
 - Some fairly straightforward
 - Others more complicated; some required judgment and/or estimation



Technical Data Set – G&C DE Cost Drivers

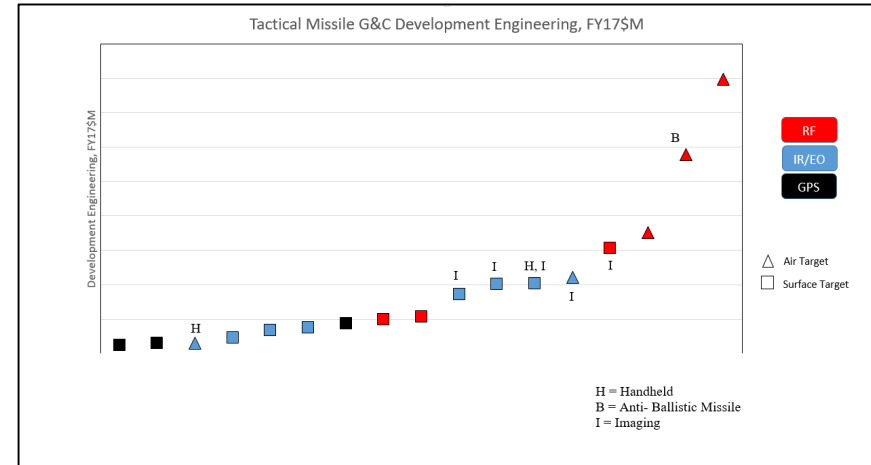


Data Assessment - Overview

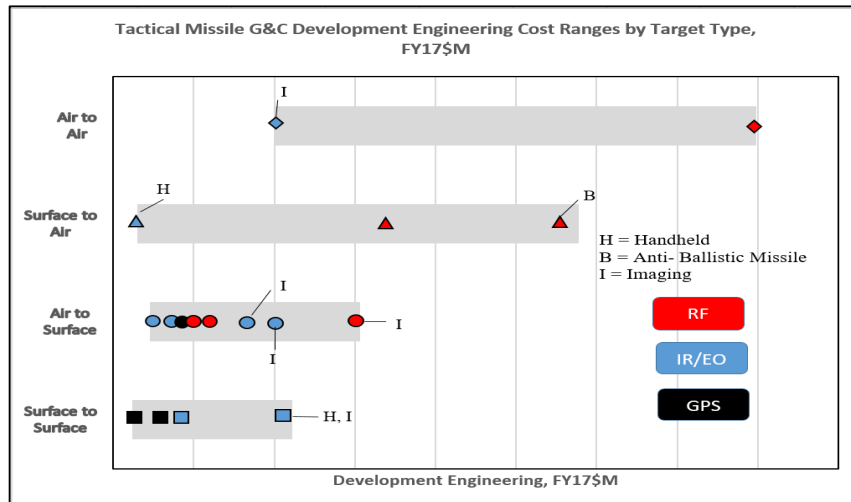
- Investigations to inform eventual data analysis:
 - Identify cost drivers, significant independent variables
 - Identify data point subgroups
 - Identify data trends
 - Identify data anomalies
 - Test data correlation
 - Identify further data gaps
- Single-variable and Multi-variable forms analyzed

Data Assessment - Visualization to Understand Data Better

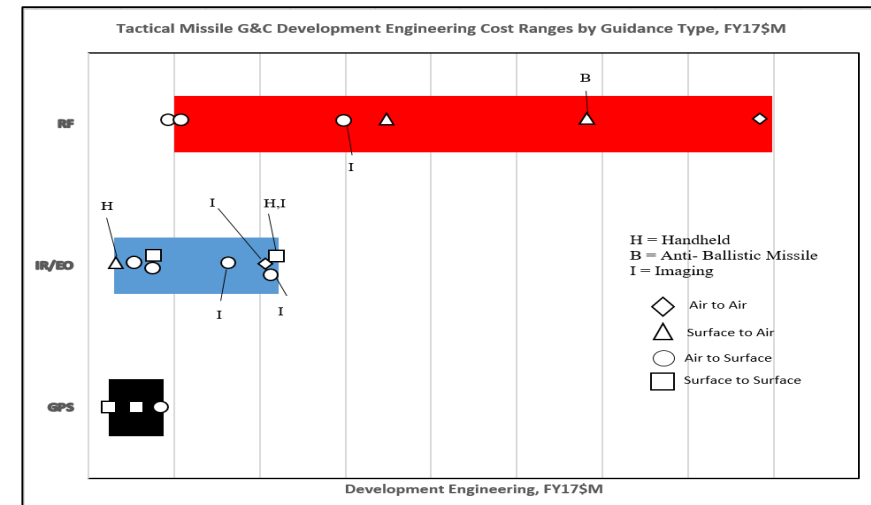
- Correlating a new technology G&C with the data set can help reduce error
 - Guidance complexity increases going from GPS to IR/EO to RF
 - Guidance complexity is generally greater for airborne targets vs surface
 - Other functions (e.g., imaging) increase cost



Scaling G&C DE Cost versus Guidance and Target Type



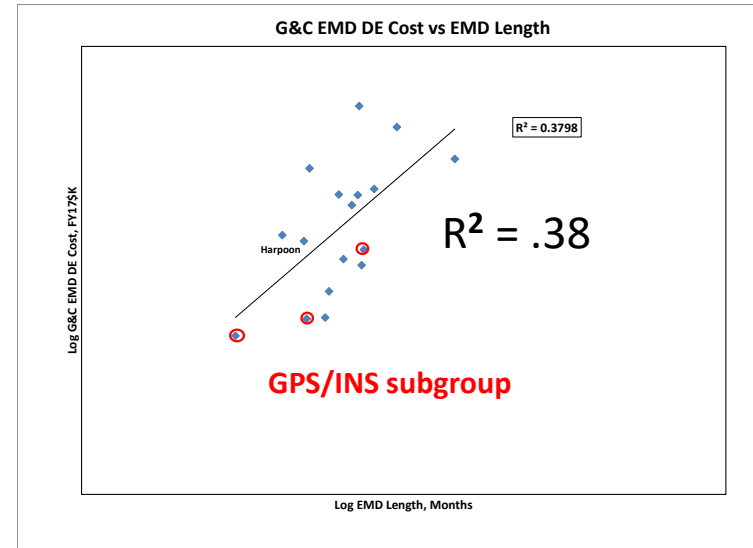
Range of G&C DE Cost Versus Target and Launch Type



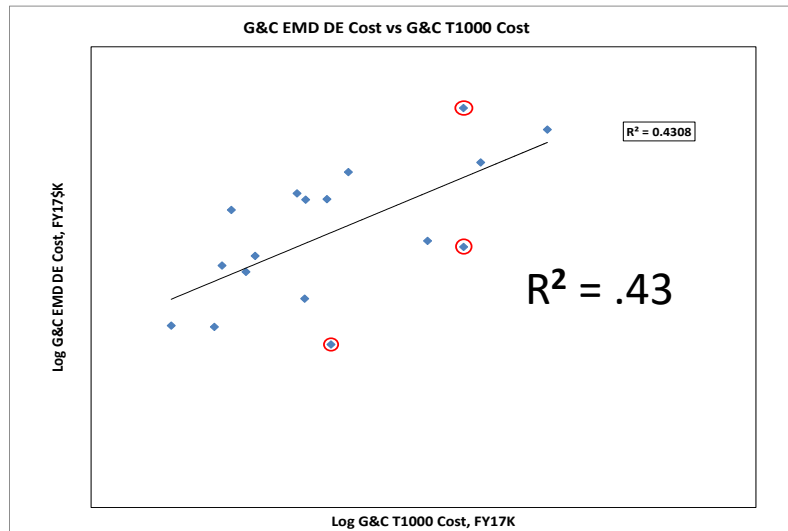
Range of G&C DE Cost Versus Guidance Type

Data Assessment - Single Variable Analysis to Identify Trends and Data Anomalies

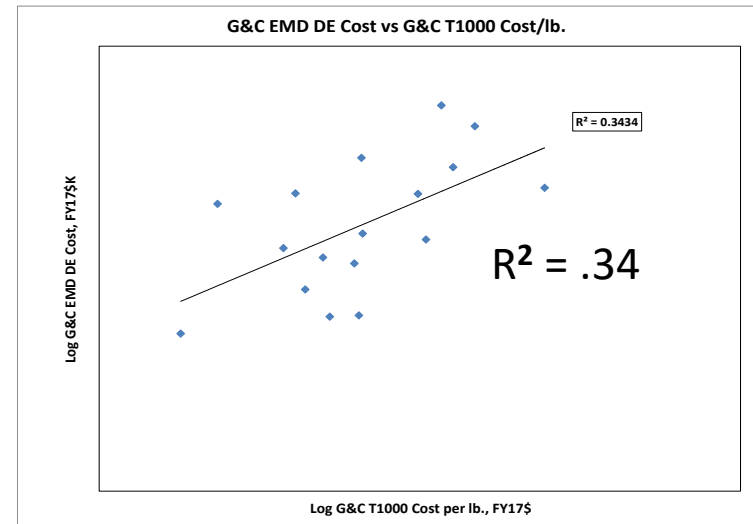
- Tested 3 Single variable correlations
 - DE Length, G&C T1000, G&C T1000 \$/lb.
- Observations
 - Some correlation, but dispersion is high
 - Indications of **outliers** or data **anomalies**
 - Possible subgroup of **GPS/INS** systems



G&C EMD DE vs EMD DE Length, Months



G&C EMD DE vs G&C T1000, FY17\$



G&C EMD DE vs G&C T1000 Cost/lb., FY17\$

CER Development - Approach

- CERs formulated with:
 - Production Start Year
 - One or more scaling variables
 - One or more missile characteristics (i.e., dummy variables)

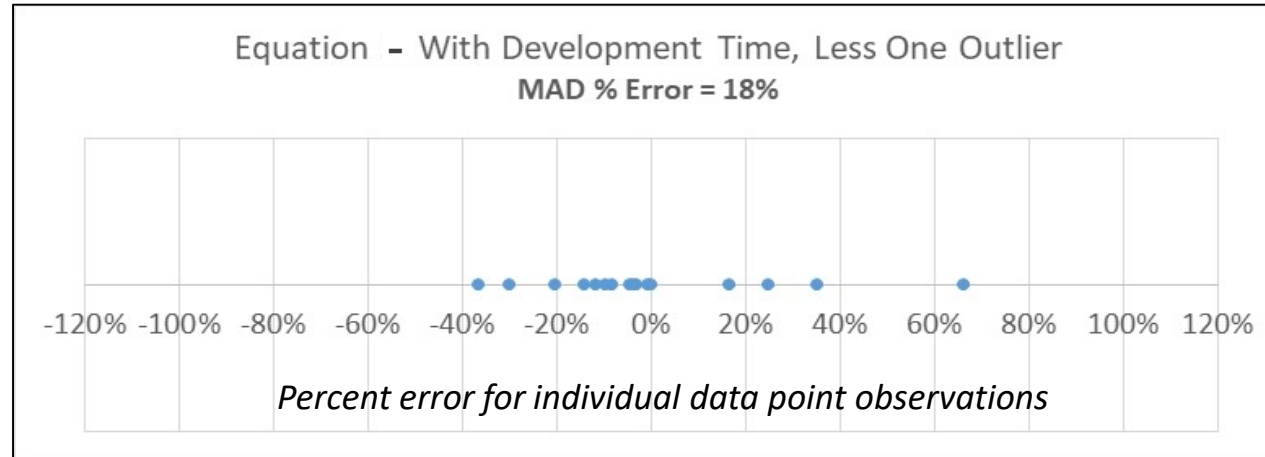
CER Form

$$\left\{ \begin{array}{l} \text{G\&C DE FY17\$K} = a \cdot \text{EXP} ((\text{Prod Start Year} - 1971) \cdot b) \cdot \text{Scaler}^c \cdot d^{\text{Characteristic} = 1 \text{ or } 0} \\ \text{Scalers} = \text{Dev Time, G\&C T1000 FY17\$K and G\&C T1000 FY17\$ per lb.} \\ \text{Characteristics} = \text{Target and Guidance Types} \end{array} \right.$$

- Two groups of CERs developed
 - With Development Time as an Independent Variable
 - Without Development Time as an Independent Variable
- For each CER group, database excursions were analyzed
 - Full database
 - Full database, but exclude one significant outlier
 - Surface targets only database

CER Development– Best Error Metric (With Development Time, Less One Outlier)

- G&C DE FY17\$K = f(Dev Time, Ballistic Missile Target, Imaging, RF Seeker)

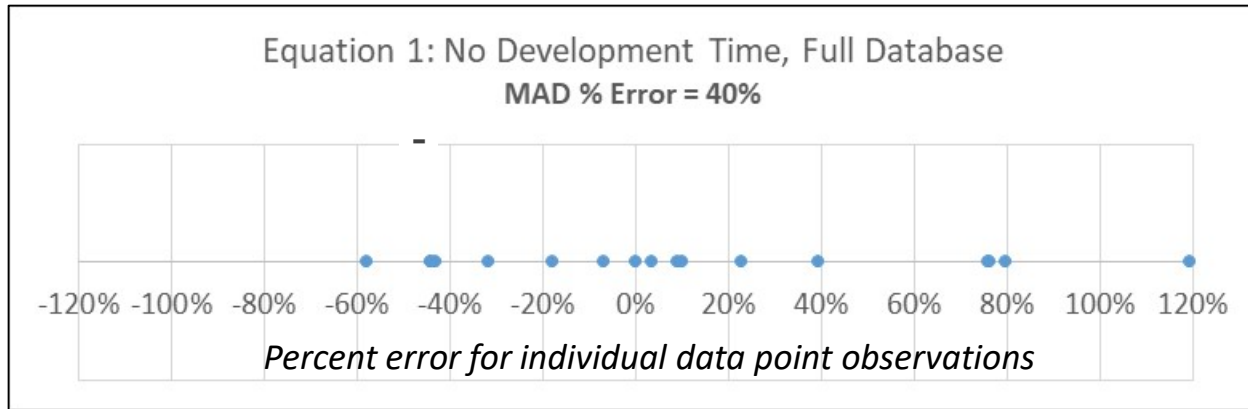


<u>Variable</u>	<u>Value</u>	<u>t-Stat</u>	<u>Prob</u>
Intercept	Constant	1.075	80%
Dev Time (months)	1.264	5.598	100%
Ballistic Missile Target	2.308	2.853	99%
Imaging Guidance	2.787	6.233	100%
RF Seeker	2.771	5.655	100%

n Observations	16
Degrees of Freedom	11
R²	.89
Median Absolute Deviation of % Errors	13%
Mean Absolute Deviation of % Errors	18%
CV	13%

CER Development – Worst Error Metric (Without Development Time, Full Database)

G&C DE FY17\$K = f(Prod Start Year, G&C\$/lb, Hand-held, Air-Air, Surface-Air, Ballistic Missile Trtgt, Imaging, RF)



n	17
DF	8
R²	.5
Median Absolute Deviation of % Errors	39%
Mean Absolute Deviation of % Errors	40%
CV	34%

<u>Variable</u>	<u>Value</u>	<u>t-Stat</u>	<u>Prob</u>
Intercept	Constant	0.460	50%
Prod Start Year	-0.029	-1.470	90%
G&C T1000 \$ per lb.	0.359	1.061	80%
Handheld	0.481	1.041	80%
Air to Air Target	2.777	1.678	90%
Surface to Air Target	1.338	1.426	90%
Ballistic Missile Target	3.396	0.918	80%
Imaging Guidance	2.338	2.525	97.5%
RF Seeker	1.807	1.553	90%

CER Development - Statistical Results

$$\text{G\&C DE FY17\$K} = a \cdot \text{EXP}((\text{Prod Start Year} - 1971) \cdot b) \cdot \text{Scaler}^c \cdot d^{\text{Characteristic} = 1 \text{ or } 0}$$

Scalers = Dev Time, G&C T1000 FY17\$K and G&C T1000 FY17\$ per lb.

Characteristics = Target and Guidance Types

	1 - No Dev Time	2 - No Dev Time *	3 - No Dev Time **	4 - Dev Time plus	5 - Dev Time plus *	6 - Dev Time plus **
	A	B	C	D	E	F
Intercept						
Production Start Year - 1971	-0.029	-0.029	-0.029			
Dev Time (months)				1.30	1.26	1.60
G&C T1000 FY17\$K						
G&C T1000 FY17\$ per lb	0.36	0.42	0.34			
Hand-held	0.48	0.38				
Air Target		1.51				
Surface Target						
Air to Air Target	2.78			2.54		
Surface to Air Target	1.34					
Air to Surface Target			1.33			
Surface to Surface Target						
Ballistic Missile Target	3.40	3.50		1.91	2.31	
Imaging Guidance	2.34	2.67	2.20	2.38	2.79	2.35
RF Seeker	1.81	1.37		3.28	2.77	3.157
EO/IR Seeker						
GPS Only						
Median Absolute Deviation of % Errors	39%	21%	17%	25%	13%	11%
Mean Absolute Deviation of % Errors	40%	32%	28%	26%	18%	19%
* Exclude Outlier						
** Only includes Surface Target G&C Systems						

Recommended CERs exhibit significantly reduced estimating error

- 18% - 40% depending on data set
- CER selection can be based on mission and use of Dev Time
- Each CER includes
 - Dev Time for that group of CERs
 - Production Start Year + T1000\$/lb. for the 2nd group of CERs
 - Plus anywhere from two to six characteristic variables
- Results for Production Start Year are highly consistent, indicating a general increase in value of 3% per year for technology advance

Data Assessment – Tabulated G&C DE Database & Error Statistics

Program	Guidance			Target Types									Guidance Types						
	Hand-held	Imaging	Ballistic Missile	Surface, No Imaging	Surface, Imaging	Air, Hand-held	Air, Not Hand-held	Surface to Surface, No Imaging	Surface to Surface, Imaging	Air to Surface, No Imaging	Air to Surface, Imaging	Surface to Air, Hand-held	Surface to Air, Not Hand-held	Air to Air	GPS Only	EO/IR Seeker, No Imaging	EO/IR Seeker, Imaging	RF Seeker, Surface	RF Seeker, Air
SYSTEM A				\$				\$							\$				
SYSTEM B				\$				\$							\$				
SYSTEM C	Y					\$						\$				\$			
SYSTEM D		Y			\$						\$						\$		
SYSTEM E				\$						\$						\$			
SYSTEM F				\$				\$								\$			
SYSTEM G				\$						\$					\$				
SYSTEM H				\$						\$								\$	
SYSTEM I				\$						\$								\$	
SYSTEM J		Y			\$						\$						\$		
SYSTEM K		Y																	\$
SYSTEM L		Y																	\$
SYSTEM M	Y	Y																	\$
SYSTEM N		Y																	\$
SYSTEM O																			\$
SYSTEM P			Y																\$
SYSTEM Q																			\$
Min				\$	\$		\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
Median				\$	\$		\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
Average				\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
Max				\$	\$		\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
n	2	6	1	7	5	1	4	3	1	4	4	1	2	2	3	3	5	2	4
Median Percent Error				29%	14%		38%	43%		12%	26%		26%	92%	56%	23%	17%	5%	40%
Average Percent Error				62%	77%		58%	57%		16%	88%		26%	92%	68%	43%	66%	5%	40%

- Database subgroup errors (i.e., difference from subgroup median and average) were developed for comparison within the database and with CER results
- Data table can be used for analogy estimating with appropriate adjustments; but . . .
- Typical and reasonable statistical results are achievable for CERs derived from the data

\$: < \$100M
 \$\$: > \$100M

Conclusions

- A CER with **EMD length (months)** has the best error metric, with a MAD% error of ~ 20%
- A CER without EMD length achieves considerably improved error metrics compared with a cost factor approach:
 - ~ 30 – 40% MAD% error vs ~ 50% to >100% factor MAD error
- The tabulated G&C EMD Development Engineering cost database organized by characteristic groupings allows a user to better understand specific statistics, cost uncertainties and database drawbacks related to the system being estimated
- The tabulated cost database can be used for a ROM, analogy or factor approach based on G&C Technology and Mission when appropriate
 - If a new development is a good fit with a subgroup of the database (i.e., similar function/characteristics)
 - COEA, AOA, Long Range Planning, etc.
 - Estimating modifications or variant development



Backup

DD Form 1921-1 Functional Cost-Hour Report

SECURITY CLASSIFICATION		Unclassified					
FUNCTIONAL COST-HOUR REPORT			Form Approved OMB No. 0704-0188				
The public reporting burden for this collection of information is estimated to average 16 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.							
1. PROGRAM a. MDAP: b. PHASE:	2. PRIME MISSION PRODUCT	3. CONTRACTOR TYPE (X One) <input type="checkbox"/> PRIME / ASSOCIATE <input type="checkbox"/> DIRECT-REPORTING SUBCONTRACTOR	4. NAME/ADDRESS (Include Zip Code)				
5. APPROVED PLAN NUMBER	6. CUSTOMER (Direct-Reporting Subcontractor Use Only)	7. TYPE ACTION a. CONTRACT NO.: b. LATEST MODIFICATION: c. SOLICITATION NO.: d. NAME:					
8. PERIOD OF PERFORMANCE a. START DATE (YYYYMMDD): b. END DATE (YYYYMMDD):	9. REPORT CYCLE <input type="checkbox"/> INITIAL <input type="checkbox"/> INTERIM <input type="checkbox"/> FINAL	10. SUBMISSION NUMBER	11. RESUBMISSION NUMBER				
12. REPORT AS OF (YYYYMMDD)	13. NAME (Last, First, Middle Initial)	14. DEPARTMENT	15. TELEPHONE NO. (Include Area Code)				
16. EMAIL ADDRESS	17. DATE PREPARED (YYYYMMDD)	18. WBS ELEMENT CODE	19. WBS REPORTING ELEMENT				
20. NUMBER OF UNITS a. TO DATE: b. AT COMPLETION:	21. APPROPRIATION <input type="checkbox"/> RDT&E <input type="checkbox"/> PROCUREMENT <input type="checkbox"/> O&M						
FUNCTIONAL DATA ELEMENTS		COSTS AND HOURS INCURRED TO DATE			COSTS AND HOURS INCURRED AT COMPLETION		
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(1) DIRECT ENGINEERING LABOR HOURS							
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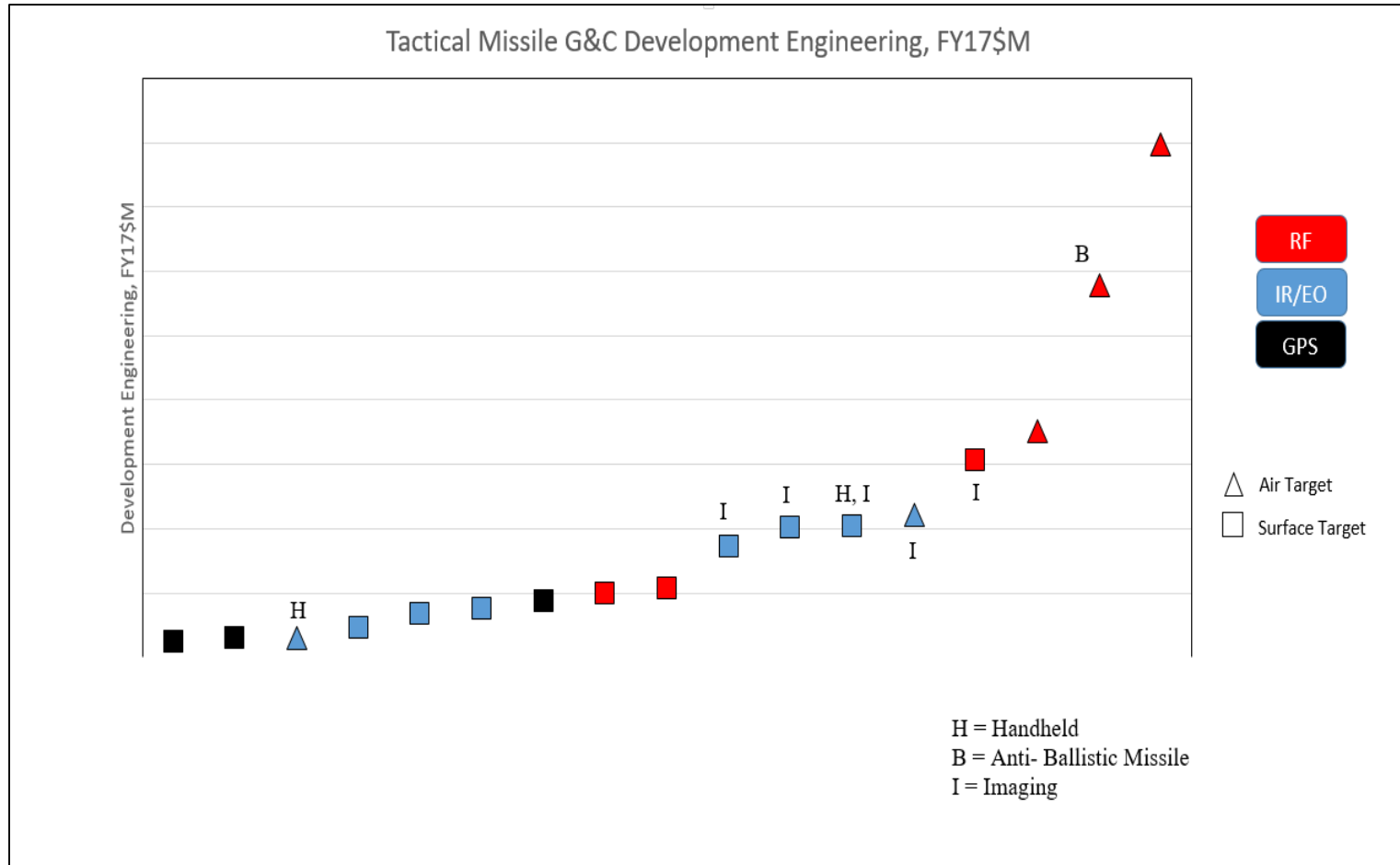
DD FORM 1921-1, 20070416

PREVIOUS EDITION IS OBSOLETE.

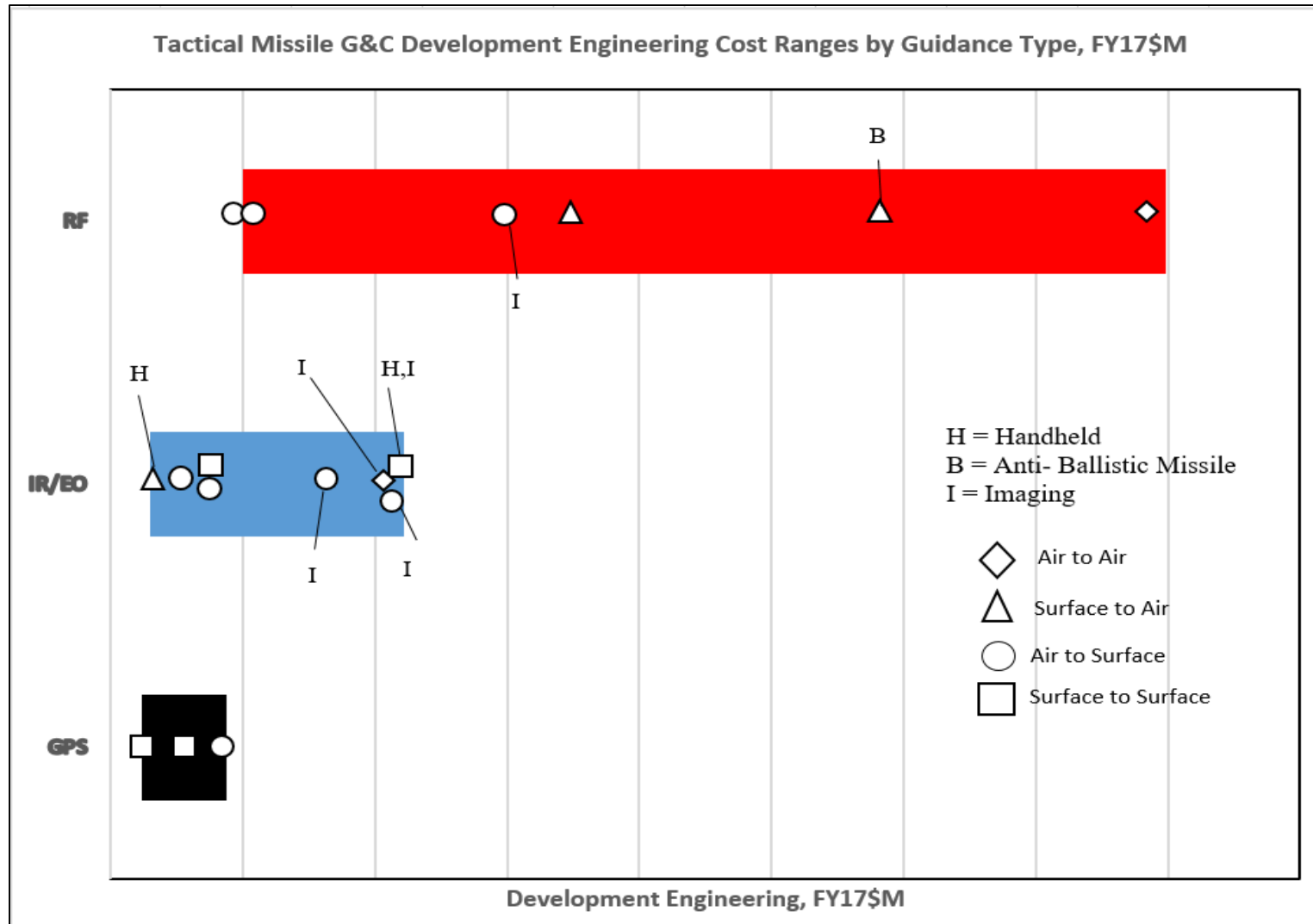
SECURITY CLASSIFICATION

Unclassified

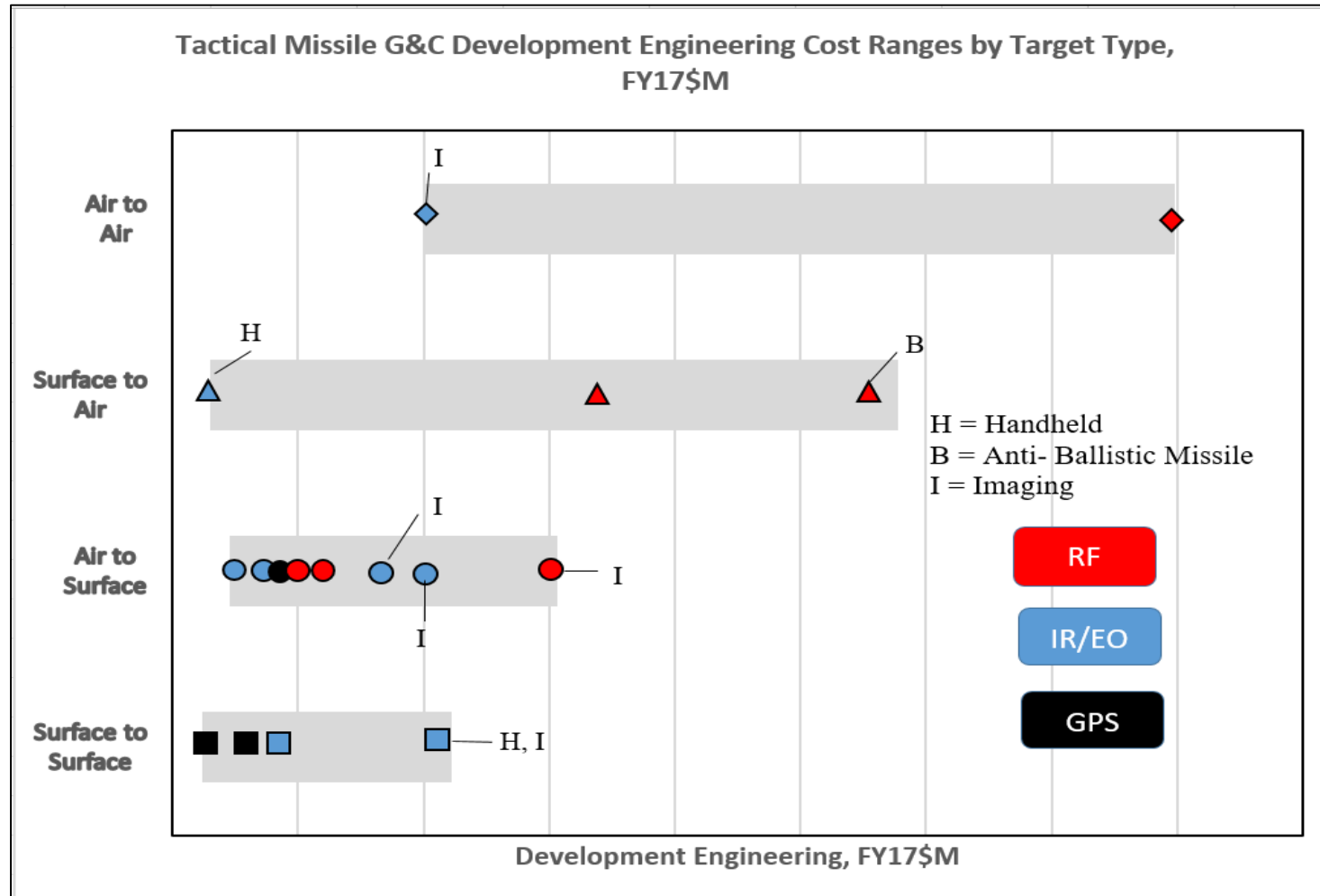
Data Assessment Scaling G&C DE Cost versus Guidance Type, Target Type & Launch Environment



Data Assessment - Range of G&C DE Cost vs Guidance Type



Data Assessment - Range of G&C DE Cost Versus Target Type and Launch Environment



G&C DE Database Correlation Matrix

	<i>G&C DE (Total) FY17\$K</i>	<i>Prod Start Year - 1971</i>	<i>Dev Time (months)</i>	<i>G&C HW T1000 FY17\$K</i>	<i>Weight, G&C (lbs)</i>	<i>G&C T1000 \$ per lb</i>	<i>Hand-held</i>	<i>Air to Air Target</i>	<i>Air to Surface Target</i>	<i>Surface to Air Target</i>	<i>Surface to Surface Target</i>	<i>Ballistic Missile Target</i>	<i>Imaging Guidance</i>	<i>RF Seeker</i>	<i>EO/IR Seeker</i>	<i>GPS Only</i>
<i>G&C DE (Total) FY17\$K</i>	1.00															
<i>Prod Start Year - 1971</i>	-0.07	1.00														
<i>Dev Time (months)</i>	0.43	-0.01	1.00													
<i>G&C HW T1000 FY17\$K</i>	0.68	-0.04	0.37	1.00												
<i>Weight, G&C (lbs)</i>	0.09	0.05	0.06	0.38	1.00											
<i>G&C T1000 \$ per lb</i>	0.40	-0.23	0.19	0.27	-0.28	1.00										
<i>Hand-held</i>	-0.13	0.08	0.05	-0.22	-0.33	0.55	1.00									
<i>Air to Air Target</i>	0.54	-0.20	0.09	0.07	-0.14	0.12	-0.13	1.00								
<i>Air to Surface Target</i>	-0.29	0.27	-0.37	-0.22	-0.15	-0.30	-0.34	-0.34	1.00							
<i>Surface to Air Target</i>	0.27	0.11	0.58	0.57	0.22	0.06	0.31	-0.17	-0.44	1.00						
<i>Surface to Surface Target</i>	-0.31	-0.26	-0.15	-0.31	0.09	0.20	0.23	-0.20	-0.52	-0.26	1.00					
<i>Ballistic Missile Target</i>	0.46	-0.28	0.28	0.80	0.15	0.27	-0.09	-0.09	-0.24	0.54	-0.14	1.00				
<i>Imaging Guidance</i>	-0.03	-0.18	-0.09	-0.35	-0.31	0.26	0.11	0.11	0.29	-0.34	-0.12	-0.18	1.00			
<i>RF Seeker</i>	0.63	0.17	0.17	0.76	0.27	0.23	-0.27	0.11	0.04	0.30	-0.41	0.34	-0.29	1.00		
<i>EO/IR Seeker</i>	-0.33	0.19	0.02	-0.53	-0.48	0.02	0.39	0.02	0.06	-0.13	0.03	-0.24	0.54	-0.70	1.00	
<i>GPS Only</i>	-0.35	-0.46	-0.24	-0.26	0.29	-0.31	-0.17	-0.17	-0.13	-0.21	0.47	-0.12	-0.34	-0.34	-0.44	1.00

Analysis Results - Approach

MISSILE CHARACTERISTICS	ABREVIATION	
G&C DE (Total) FY17\$K	G&C	
Production Start Year - 1971	Year	} Scalers
Development Time (months)	DevTime	
G&C T1000 UC FY17\$K	FY17\$K	
G&C T1000 UC FY17\$K per lb.	Cost_lb	
Air Target	AT	} Target Type
Surface Target	ST	
Ballistic Missile Target	BMT	
Air-to-Air Target	AAT	} Launch/Target Type
Surface-to-Air Target	SAT	
Air-to-Surface Target	AST	
Surface-to-Surface Target	SST	
RF Seeker	RF	} Guidance Type
EO/IR Seeker	IREO	
GPS Only	GPS	
Imaging Guidance	IG	} Other
Hand-held	HH	

- Scaling and characteristic (i.e., dummy) variables were organized into groups
 - Track/monitor their use
 - Specify baseline characteristic for dummy variable groups
 - Assess results