Missile
Cost Research Literature Review

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1: EXECUTIVE SUMMARY

As a major weapon commodity, the cost of missiles is a topic of perpetual interest. As such the Services and DoD periodically invest in cost research and cost estimating methodologies for missiles. This literature review is a survey of published missile-related cost estimating methodology and database development. The focus was on research and databases developed in the past decade.

The overall strength of the current research is the relative comprehensive nature of the datasets relative to the potential population of observable programs. The AFCAA Missile Systems Sufficiency Handbook and the ODACA- CE Tactical Missle Bluebook and Cost Model Overview are common threads in missile cost research and have been sustained and updated through the last ten years. The overall shortcoming is the depth and breadth in the cost-driving technical characteristics at the subsystem level. Earlier studies from the 1990s had greater emphasis on developing CERs for different seekers and propulsion types that has since been lost.

Future weapon cost databases updates should include more systematic collection of technical data and greater granularity in air vehicle subsystem data to allow analysts to more easy distinguish between key high-cost components for weapons, such as seekers. In addition, improved capture of government program management and test & evaluation costs is needed. Given the advancements in uncertainty analysis, more emphasis is needed on both collecting schedule data and developing uncertainty ranges as part of the CER development processFinally, missile operating and maintenance cost process and cost data needs to be collected and analyzed.

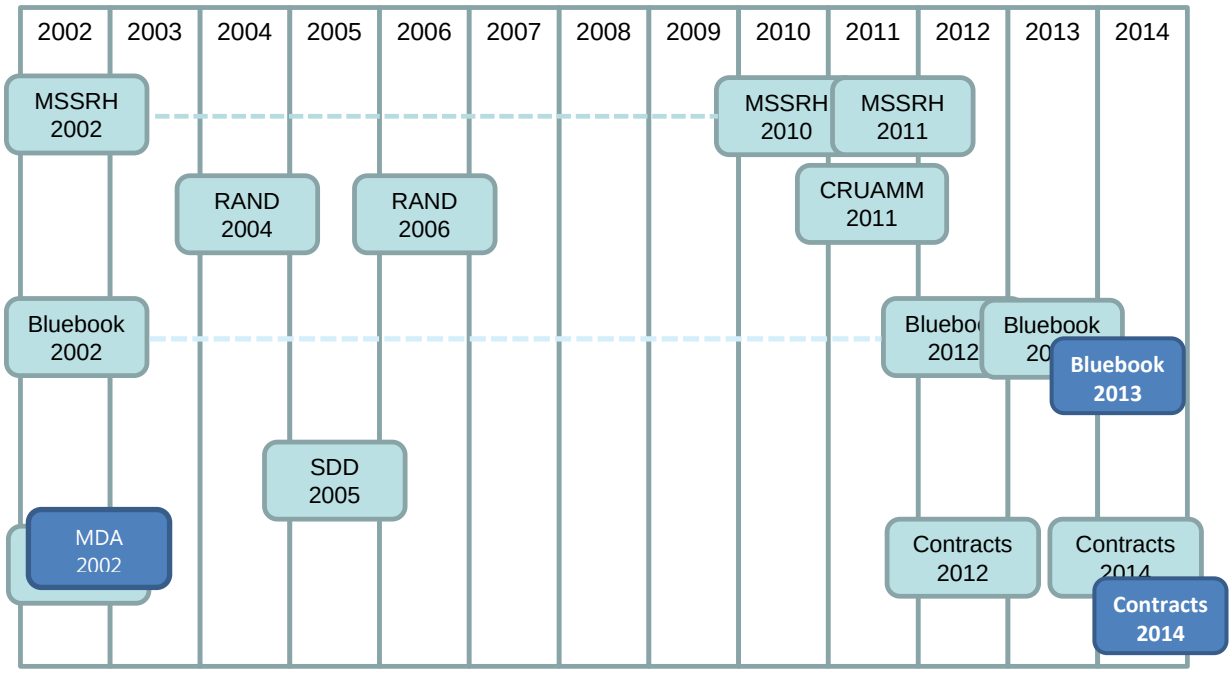
This literature review is an update and revision to CR-1631 Missile Cost Research Literature Review developed by Jeff McDowell and Darryl Arnold of Tecolote, dated March 21, 2014, sponsored by NCCA.

2: HISTORIC COST RESEARCH

The research in missile cost estimating is marked by progressively enlarged datasets accompanied with broadening outcomes in cost estimating methodologies. The following studies were reviewed and they capsulize the current state of the art in missile cost research. They are listed chronologically and the text in parenthesis following each title is an abbreviation used to reference it throughout the remainder of this document. Some of the studies address more commodities than missile systems but this document will only address the study content pertaining to missiles.

1. CR-1147 Missile Systems Sufficiency Review Handbook, Tecolote Research, Inc. for AFCAA, 2002 (MSSRH 2002)
2. CR-1171 Missile Bluebook Update, Tecolote Research, Inc. for ODASA-CE, 2002 (Bluebook 2002)
3. Test and Evaluation Trends and Costs for Aircraft and Guided Weapons, RAND for Project Air Force, 2004 (RAND 2004)
4. TN-0202 Cost Improvement Slopes for Missile Acquisition Programs, for MDA, 2002 (MDA 2002)
5. CR-1229 System Development & Demonstration Phase Development Engineering Cost Methodology, Tecolote Research, Inc. for ODASA-CE, 2005 (SDD 2005)
6. Systems Engineering and Program Management Trends and Costs For Aircraft and Guided Weapons, RAND for Project Air Force, 2006 (RAND 2006)
7. CR-1461 Missile Systems Sufficiency Review Handbook, Tecolote Research, Inc. for AFCAA, 2010 (MSSRH 2010)
8. CR-1461/2 Missile Systems Sufficiency Review Handbook, Tecolote Research, Inc. for AFCAA, 2011 (MSSRH 2011)
9. CR-1501/1 Cost Risk and Uncertainty Analysis Metrics Manual (CRUAMM) including a Missile Appendix, Tecolote Research, Inc. for AFCAA, 2011(CRUAMM 2011)
10. Tactical Missile Bluebook and Cost Model Overview, MCR DODCAS Briefing, 2012 (Bluebook 2012)
11. Contract Price & Schedule Database, Technomics, DODCAS Briefing, 2012 (Contracts 2012)
12. Tactical Missile Bluebook: Cost Estimating Relationships & Factors, MCR Federal, Inc. for ODASA-CE, 2013 (Bluebook 2013)
13. Interactive Contract Database and Analysis Tool, Technomics, AFCAA Briefing, 2014 (Contracts 2014)

The following figure depicts a timeline of the studies examined. The MSSRH 2002 and Bluebook 2002 are slightly older than ten years but marks the beginning of notable study threads. The MSSRH studies share a common thread of datasets and the Bluebooks share a common thread of datasets. Though these are depicted as distinct threads, the MSSRH and Bluebook dataset's content overlap. The primary difference across the versions is the number of data points. Additionally, the work breakdown structure was modified to increase the granularity of hardware. Therefore, the MSSRH 2002 to 2011 and the Bluebook 2002 to 2013 threads will be each treated via a single entry within this review. Similarly, Contracts 2014 is an update to Contracts 2012 and the literature review reflects the Contracts 2014 revision.



Two additional earlier studies of note are CR-1036 AFCAA Missile and Munitions CER Development Study, March 2000 and CR-1057 USACEAC Missile Production Cost Factors, January 2001. These two legacy documents are not reviewed herein, however, the essence of these studies is captured in MSSRH 2002.

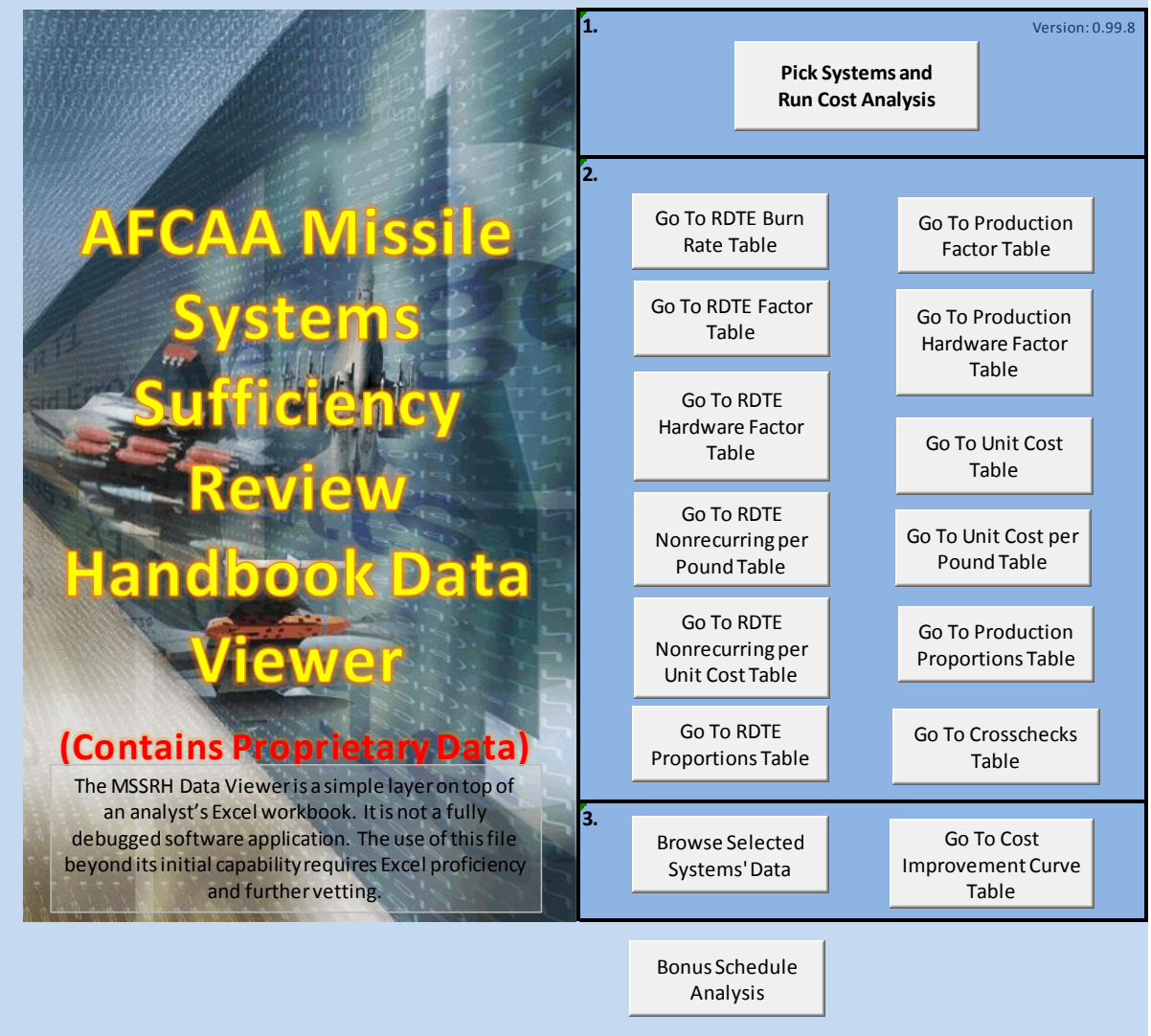
2.1 CR-1147 "MISSILE SYSTEMS SUFFICIENCY REVIEW HANDBOOK", TECOLOTE RESEARCH, INC. FOR AFCAA, 2002 (MSSRH 2002); CR-1461 "MISSILE SYSTEMS SUFFICIENCY REVIEW HANDBOOK", TECOLOTE RESEARCH, INC. FOR AFCAA, 2010 (MSSRH 2010); AND CR-1461/2 "MISSILE SYSTEMS SUFFICIENCY REVIEW HANDBOOK", TECOLOTE RESEARCH, INC. FOR AFCAA, 2011 (MSSRH 2011)

The MSSRH 2002, 2010, and 2011 series was developed to assist cost analysts in the performance of cost estimate sufficiency reviews of missile systems. It is a guide that provides the analyst with historically-based information allowing them to conduct checks for overall reasonableness of the cost estimating methodologies under review.

MSSRH 2011 includes additional datapoints and is an update of MSSRH 2010 which was, in turn, an update of MSSRH 2002. The handbook documents data collection and analysis efforts including recommended cost-to-cost average factors, ranges of cost-to-cost factors, average cost improvement curve slopes, and ranges on cost improvement curves slopes. It also provides general rules-of-thumb such as dollars per pound and durations between milestones.

The handbook includes data sets and metrics for the performance of a sufficiency reviews. Typically, a sufficiency review of a cost estimate is performed at a summary level to determine its adequacy and to identify areas of potential cost risk. This is done by comparing the estimating methodologies or parameters in the cost estimate of interest against a set of general well founded and historically based "standard" values for reasonableness and completeness. The standard values are typically broad since the underlying data supporting them is often broad. Notwithstanding the wide variation in the raw cost data, these guidelines do provide a sound basis for a reasonableness check of an estimate. The metrics within this handbook are not intended to be primary estimating methodologies, but as a starting point for a tailored analysis suitable for evaluating or corroborating an estimate.

An interface is included in the Excel spreadsheet where missile programs in the dataset can be viewed in various ways, including filters based on technical parameters (weight, speed, length, diameter, range or by platform (air, surface) or mission (air, surface, missile defense). Data analysis can be sorted by type of guidance (LASER, EO, IR, multimode, active or passive RADAR, etc.), type of warhead (nuclear, bomblets, penetrator, general purpose bomb, etc.), or missile propulsion, lead service and control. Below is a picture of the interface.



2.1.1 DESCRIPTION OF DATASET

Data used in MSSRH 2011 is comprised of RDT&E and production data from Army, Navy, and Air Force missile systems. These studies addressed the full cost element structure (CES) of the development and production phases.

The efforts of the most recent study (2011) have increased the number of development data points to 66. This is an increase from the original 28 (in 2002) and 56 (in 2010). The efforts increased the number of production data points to 207 production lots. This is an increase from the original 85 (in 2002) and 171 (in 2010). Additionally the work breakdown structure was modified to increase the granularity of hardware subsystems.

The MSSRH dataset is proprietary and is managed by AFCAA. The dataset includes MS Excel® workbooks that contain the cost information for the historical programs as a collection of raw and normalized data that has been mapped to the standard RDT&E and Production CESs. The primary types of data are CCDRs and CPRs largely from the ACDB's Tri-Service Missile Database.

The following table shows the scope of the information in the dataset for development programs. An "x" indicates data exists and was used in the analysis.

Missile \ STANDARD WBS	Missile System Costs	Prime Mission Product (PMP)	PMP NonRec	PMP Rec	System Engineering/Program Management (SE	System Engineering	Program Management	Other SEPM	System Test And Evaluation	Training	Data	Support Equipment	Initial Spare And Repair Parts	Other Missile System	Development Facilities	Producibility, Engineering, and Planning (PE	Tooling	Operational/Site Activation	Other Other	Residual Missile System		Schedule Information	Technical/Perfomance Data	Government Costs
AAAM	x	x	x		x	x	x		x	x	x	x								x			x	
ACM (129A-B)	x	x	x	x						x		x	x							x			x	
ALCM (AGM-86)	x	x	x	x	x	x	x	x	x	x	x	x		x			x			x			x	
AMRAAM (AIM-120A-D)	x	x	x	x	x	x	x		x	x	x	x	x	x			x	x	x	x			x	
APKWS	x	x	x	x	x	x	x	x	x					x					x	x			x	
ASALM Technology Validatio	x	x	x	x	x	x	x		x		x	x	x							x			x	
ATACMS (MGM-140)	x	x	x	x	x	x	x	x	x	x	x	x		x		x				x			x	
CEM (CBU-87)	x	x	x	x	x	x	x		x		x			x	x		x			x			x	
ERIS	x	x	x		x	x	x		x		x	x								x			x	
Excalibur (M-982)	x	x	x	x	x	x	x		x					x			x			x			x	
GMLRS DPICM	x	x	x	x	x	x	x	x	x			x		x		x	x			x			x	
GMLRS Unitary	x	x	x	x	x	x	x		x	x		x		x			x			x			x	
HARM (AGM-88)	x	x	x	x	x	x	x	x	x		x	x		x			x			x			x	
Harpoon (AGM-84)	x	x	x	x	x	x	x	x	x		x	x								x			x	
HEDI	x	x	x		x	x	x		x		x	x	x							x			x	
Hellfire (AGM-114)	x	x	x		x		x		x	x	x	x								x			x	
JASSM (AGM-158)	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x		x	x			x	
Javelin (FGM-148)	x	x	x	x	x	x	x	x	x	x	x	x								x			x	
JDAM (GBU-31)	x	x	x	x	x	x	x	x	x	x		x		x	x		x			x			x	
JSOW (154A)	x	x	x	x	x	x	x	x	x	x	x	x		x			x			x			x	
Longbow Hellfire (AGM-114I	x	x	x	x	x	x	x	x	x	x	x									x			x	
LOSAT (MGM-166)	x	x	x	x	x	x	x	x	x	x		x								x			x	
Maverick IIR (AGM-65)	x	x	x	x	x	x	x		x	x	x	x								x			x	
Maverick Optical (AGM-65)	x	x	x	x	x	x	x		x	x	x	x								x			x	
MLRS (M270)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x			x	
Patriot (MIM-104)	x	x	x		x	x	x	x	x	x		x	x	x		x	x			x			x	
Pershing II	x	x	x		x			x	x	x	x	x	x							x			x	
Phoenix (AIM-54A)	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x			x			x	
Powered (GBU-15)	x	x	x		x	x	x		x	x	x	x								x			x	
SADARM	x	x	x	x	x	x	x				x									x			x	
SDB (GBU-39)	x	x	x	x	x	x	x		x	x	x	x		x			x		x	x			x	
SFW (CBU-97)	x	x	x		x	x	x		x	x	x									x			x	
Sidewinder (AIM-9X)	x	x	x	x	x	x			x		x	x								x			x	
SLAM-ER (UGM-109)	x	x	x		x	x	x	x	x	x	x	x	x	x			x	x		x			x	
SLAT (AQM-127)	x	x	x	x	x	x	x	x	x	x	x	x								x			x	
Sparrow (AIM-7F)	x	x	x	x					x		x	x	x							x			x	
Sprint	x	x	x	x	x			x	x		x	x	x							x			x	
SRAM (AGM-69)	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x			x			x	
Stinger (FIM-92)	x	x	x	x	x	x	x		x	x	x	x		x		x	x			x			x	

The following table breaks out development PMP (both nonrecurring and recurring) showing where data has been collected and used in the analysis.

Missile / STANDARD WBS	Prime Mission Product (PMP)	PMP NonRec	Air Vehicle NonRec	Command And Launch NonRec	Integration NonRec	Other PMP NonRec	Residual PMP NonRec	PMP Rec	Air Vehicle Rec	Propulsion Rec	Payload Rec	Airframe Rec	Guidance And Control Equipment Rec	Telemetry Rec	Integration, Assembly, Test, And Checkout	Container Rec	Other Air Vehicle Rec	Command And Launch Rec	Integration Rec	Other PMP Rec
AAAM	x	x	x	x																
ACM (129A-B)	x	x	x			x		x												x
ALCM (AGM-86)	x	x	x	x				x	x			x	x	x	x	x		x		
AMRAAM (AIM-120A-D)	x	x	x	x	x			x	x	x	x	x	x	x	x		x	x		
APKWS	x	x	x		x			x	x				x		x	x	x		x	
ASALM Technology Validatio	x	x	x	x				x	x				x		x			x		
ATACMS (MGM-140)	x	x	x		x			x	x	x	x	x	x	x	x	x			x	x
CEM (CBU-87)	x	x	x					x	x		x				x					
ERIS	x	x	x	x																
Excalibur (M-982)	x	x	x					x	x		x		x	x	x	x				
GMLRS DPICM	x	x	x	x			x	x	x	x	x		x		x					
GMLRS Unitary	x	x	x	x				x	x	x	x		x	x	x			x		
HARM (AGM-88)	x	x	x	x				x	x			x	x	x			x	x		
Harpoon (AGM-84)	x	x	x	x				x	x	x	x	x	x		x			x		
HEDI	x	x	x																	
Hellfire (AGM-114)	x	x	x	x	x															
JASSM (AGM-158)	x	x	x	x				x	x	x	x	x	x	x	x	x		x		
Javelin (FGM-148)	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x		
JDAM (GBU-31)	x	x	x	x	x			x	x			x	x	x	x	x		x	x	
JSOW (154A)	x	x	x	x	x			x	x		x	x	x	x	x					
Longbow Hellfire (AGM-114L	x	x	x					x	x	x	x		x	x	x	x				
LOSAT (MGM-166)	x	x	x	x	x	x		x	x				x				x	x	x	x
Maverick IIR (AGM-65)	x	x	x	x				x	x			x	x		x			x		
Maverick Optical (AGM-65)	x	x	x	x	x			x	x			x	x	x				x		
MLRS (M270)	x	x	x	x				x												
Patriot (MIM-104)	x	x	x	x																
Pershing II	x	x	x	x																
Phoenix (AIM-54A)	x	x	x	x		x		x	x	x	x	x	x	x			x	x		x
Powered (GBU-15)	x	x	x		x															
SADARM	x	x	x					x	x		x		x			x	x			
SDB (GBU-39)	x	x	x	x	x			x	x		x	x	x		x	x		x		
SFW (CBU-97)	x	x	x																	
Sidewinder (AIM-9X)	x	x	x					x	x				x							
SLAM-ER (UGM-109)	x	x	x	x																
SLAT (AQM-127)	x	x	x	x		x		x	x	x		x	x				x			x
Sparrow (AIM-7F)	x	x	x					x	x	x		x	x				x			
Sprint	x	x	x	x	x			x	x	x	x	x	x	x	x			x		
SRAM (AGM-69)	x	x	x	x				x	x								x	x		
Stinger (FIM-92)	x	x	x	x		x		x												

The following table shows the scope of the information in the dataset for production programs.

2011 Missile Sufficiency Review Data - Prod

Missile \ STANDARD WBS	# of Lots	Missile System	Prime Mission Product (PMP)	PMP NonRec	PMP Rec	System Engineering/Program Management (SEPM)	System Engineering	Program Management	Other SEPM	System Test And Evaluation	Training	Data	Support Equipment	Initial Spare And Repair Parts	Other Missile System	Development Facilities	Producibility, Engineering, and Planning (PEP)	Tooling	Operational/Site Activation	Modifications	Other Other	Residual Other		Schedule Information	Technical/Perfomance Data	Government Costs
ACM (AGM-152)	4	x	x	x	x	x			x	x	x	x	x	x	x				x						x	
ALCM (AM-86)	5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x						x	
AMRAAM (AIM-120)	21	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x				x	
ATACMS (MGM-140)	11	x	x	x	x	x	x	x		x	x	x	x	x	x			x			x				x	
CEM (CBU-87) Aerojet	4	x	x		x	x	x	x		x		x			x			x			x				x	
CEM (CBU-87) Honeywell	4	x	x	x	x	x	x	x		x		x			x			x		x	x				x	
GMLRS (DPICM) (M-30)	5	x	x	x	x	x	x	x		x	x		x		x			x							x	
GMLRS (UNITARY) (M-31)	3	x	x	x	x	x	x	x		x			x												x	
HARM (AGM-88)	11	x	x	x	x	x			x		x	x	x	x	x						x				x	
Hellfire (AGM-114) Martin	7	x	x		x	x	x	x		x	x	x			x						x				x	
Hellfire (AGM-114) Rockwell	10	x	x		x	x	x	x		x	x		x		x			x							x	
JASSM (AGM-158A)	7	x	x		x	x	x	x							x						x				x	
Javelin (FGM-148)	4	x	x	x	x	x			x	x	x	x		x	x						x				x	
JSOW (AGM-154A)	8	x	x		x	x	x		x	x		x	x		x			x			x				x	
JSOW LRIP 1 (AGM-154C1)	6	x	x	x	x	x	x		x	x		x	x		x			x			x	x			x	
Longbow Hellfire (AGM-114L)	4	x	x	x	x	x	x	x	x	x		x		x	x	x									x	
Maverick (AGM-65A)	3	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x			x	
Maverick IIR (AGM-65D) Hughes	8	x	x	x	x	x	x	x	x		x	x		x	x			x							x	
Maverick IIR (AGM-65D) Raytheon	6	x	x	x	x	x	x	x		x		x			x			x			x				x	
MLRS (M-26)	12	x	x		x	x	x	x		x	x	x	x	x	x	x		x			x				x	
Patriot (MIM-104)	7	x	x		x	x			x	x	x		x												x	
Phoenix (AIM-54A)	9	x	x	x	x	x	x			x	x	x	x	x											x	
SFW (CBU-97A/B)	3	x	x	x	x	x	x	x			x	x			x		x	x			x				x	
Sidewinder (AIM-9X)	10	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x				x	
Sparrow (AIM-7M)	9	x	x	x	x	x			x			x		x	x			x			x				x	
Sparrow III (AIM-7F) Raytheon	8	x	x		x	x			x			x		x	x						x				x	
Stinger Basic with POST (FIM-92A-C)	15	x	x	x	x	x	x	x		x	x		x	x	x						x				x	
Tomahawk SLCM (UGM-109A-C)	3	x	x	x	x	x	x		x	x	x	x	x	x	x			x		x	x				x	

The following table breaks out production PMP (both nonrecurring and recurring) showing where data has been collected and used in the analysis.

Missile \ STANDARD WBS	Prime Mission Product (PMP)	PMP NonRec	Air Vehicle NonRec	Propulsion NonRec	Payload NonRec	Airframe NonRec	Guidance And Control Equipment NonRec	Telemetry NonRec	Integration, Assembly, Test, And Checkout NonRec	Container NonRec	Other Air Vehicle NonRec	Residual Air Vehicle NonRec	Command And Launch NonRec	Integration NonRec	Other PMP NonRec	PMP Rec	Air Vehicle Rec	Propulsion Rec	Payload Rec	Airframe Rec	Guidance And Control Equipment Rec	Telemetry Rec	Integration, Assembly, Test, And Checkout Rec	Container Rec	Other Air Vehicle Rec	Command And Launch Rec	Integration Rec	Other PMP Rec
ACM (AGM-152)	x	x	x								x					x	x								x			x
ALCM (AM-86)	x	x	x		x	x	x	x	x		x					x	x	x	x	x	x	x	x	x	x			x
AMRAAM (AIM-120)	x	x	x								x					x	x	x	x	x	x	x	x	x	x			
ATACMS (MGM-140)	x	x	x		x	x	x		x	x				x		x	x		x	x	x		x	x			x	
CEM (CBU-87) Aerojet	x															x	x		x	x	x		x	x	x			
CEM (CBU-87) Honeywell	x	x	x		x	x										x	x		x	x			x	x				
GMLRS (DPICM) (M-30)	x	x	x	x	x	x	x		x							x	x	x	x	x	x		x					
GMLRS (UNITARY) (M-31)	x	x	x		x	x	x		x							x	x	x	x	x	x		x					
HARM (AGM-88)	x	x	x								x					x	x	x	x	x	x				x		x	
Hellfire (AGM-114) Martin	x															x	x	x	x		x		x		x			x
Hellfire (AGM-114) Rockwell	x															x	x	x	x		x	x	x	x	x	x		
JASSM (AGM-158A)	x															x	x	x	x	x	x		x	x				
Javelin (FGM-148)	x	x	x	x	x		x	x	x	x			x			x	x	x	x		x	x	x	x		x		
JSOW (AGM-154A)	x															x	x		x	x	x	x	x	x	x		x	
JSOW LRIP 1 (AGM-154C1)	x	x	x				x									x	x		x	x	x	x	x	x			x	
Longbow Hellfire (AGM-114L)	x	x	x	x	x		x		x	x			x		x	x	x	x	x		x		x	x		x		x
Maverick (AGM-65A)	x	x	x	x	x	x	x			x		x	x		x	x	x	x	x	x	x			x		x		x
Maverick IIR (AGM-65D) Hughes	x	x	x			x	x				x				x	x	x			x	x		x		x			
Maverick IIR (AGM-65D) Raytheon	x	x	x	x		x	x		x							x	x	x	x	x	x	x	x		x			x
MLRS (M-26)	x															x	x	x	x				x	x	x	x		
Patriot (MIM-104)	x															x	x	x	x		x	x	x	x	x	x		
Phoenix (AIM-54A)	x	x	x								x					x	x	x		x	x				x	x		x
SFW (CBU-97A/B)	x	x	x	x	x	x	x		x	x						x	x	x	x	x	x		x	x				
Sidewinder (AIM-9X)	x	x	x	x	x	x	x	x	x		x					x	x	x	x	x	x	x	x	x	x			
Sparrow (AIM-7M)	x	x	x								x					x	x			x	x		x	x				
Sparrow III (AIM-7F) Raytheon	x															x	x		x	x	x		x					
Stinger Basic with POST (FIM-92A-C)	x	x	x					x			x		x			x	x	x			x	x	x	x		x		x
Tomahawk SLCM (UGM-109A-C)	x	x	x		x						x					x	x	x	x	x			x	x	x	x		

O&S costs are not included in this study.

2.1.2 DESCRIPTION OF CERS

MSSRH contains many different analyses including:

- Cost Element Distribution Statistics for the RDT&E and production cost elements;

- Production "Declining Factors" for estimating production lot costs for Recurring Engineering, Sustaining Tooling, Quality Control, System Test and Evaluation, Systems Engineering/Program Management, Training, and Data;
- Learning curve metrics for missile propulsion, payload, airframe guidance and control subsystems as well as integration and assembly;
- Rough-order magnitude relationships on Prime Mission Product (PMP) hardware cost estimates based on weight. Cost per pound values have been normalized to unit cost at the 100th unit
- Time Phasing recommendations.
- All of the costs are in thousands of FY2008 dollars includes G&A and excludes fee.

Fitted equations for use as Cost Estimating Relationships were NOT developed in the course of the study.

The following table summarizes key factors developed and provided for analyst use:

Sufficiency Handbook Cost Analysis			
Available Cost Anaysis	**Development**	**Production**	**O&S**
WBS Cost Breakdown	X	X	
Cost-Cost Factor	X	X	
Learning Curve Slope	X	X	
Range for Cost Factor	X		
Range for Learning Curve	X		
Non Recurring/Recurring Ratio	X		
Burn Rate by Cost Element	X		
Cost Element as % of Recurring		X	
Cost Declining Factor by Lot		X	
Quantity Slope Statistics		X	
Cost per Pound(LB) Rule of Thumb		X	
Schedule (Duration) Statistics		X	
Schedule Growth		X	

The primary cost drivers throughout the MSSRH were missile subsystem weights and phase durations. The study provides a historically-based set of selected cost-to-cost factors, cost improvement curve slopes (with and without rate), cost per pound metrics for select cost elements, and spend rate inputs to the beta distribution. Much of the information is presented

in pairs of tables. The first table presents the median values which represent the central tendency of the data. These are recommended for use as point estimates.

	Median
System Engineering/Program Management (SEPM)	
System Engineering	
Program Management	
Other SEPM	
System Test And Evaluation	
Training	
Data	
Support Equipment	
Initial Spare And Repair Parts	
Other Missile System	
Development Facilities	
Producibility, Engineering, and Planning (PEP)	
Tooling	
Engineering Changes	
Operational/Site Activation	
Training Ammunition/Missiles	
War Reserve Ammunition/Missiles	
Modifications	
Other Other	

The second table in each pair presents a detailed range of descriptive statistics by rows matching the first table.

	Count	Mean	Std Dev	Mean Minus 1 Std Dev	Mean Plus 1 Std Dev	Low	15-precentile	Median	85-percentile	High	CV	Lognormal Mean	Lognormal: Mean Minus 1 Std Dev	Lognormal: Mean Plus 1 Std Dev
System Engineering/Program Management (SEPM)														5
System Engineering														4
Program Management														4
Other SEPM														0
System Test And Evaluation														1
Training														8
Data														3
Support Equipment														9
Initial Spare And Repair Parts														2
Other Missile System														7
Development Facilities														4
Producibility, Engineering, and Planning (PEP)														
Tooling														7
Engineering Changes														
Operational/Site Activation														6
Training Ammunition/Missiles														
War Reserve Ammunition/Missiles														
Modifications														
Other Other														1

The methodologies address the full Cost Element Structure (CES) of the Development and Production phases.

The paired tables include the following analyses:

- RDT&E Factor of System PMP Cost
- RDT&E Nonrecurring Factor of Recurring Cost
- RDT&E Nonrecurring Cost per Pound (UC100)
- RDT&E Nonrecurring Cost per UC100 Cost
- RDT&E Nonrecurring Cost per T1 Cost
- RDT&E Burn Rate
- RDT&E Phase Proportions
- Production Factor of Systyem PMP Cost
- Production Nonrecurring Factor of Recurring Cost
- Production Phase Proportions

2.1.3 STRENGTHS AND WEAKNESSES

The significant strength of MSSRH is that the dataset includes 66 development and 207 production data points and includes data from all three services. Most of the standard Cost Element Structure elements are represented in the dataset.

2.2 CR-1171 "1993 MISSILE BLUEBOOK UPDATE", TECOLOTE RESEARCH, INC FOR ODASA-CE, 2002 AND "TACTICAL MISSILE BLUEBOOK: COST ESTIMATING RELATIONSHIPS & FACTORS", MCR FEDERAL, INC FOR ODASA-CE, 2013

The 2002 Bluebook is an update an earlier study[1] with more current data. The 2002 Bluebook contains the results of data collection, normalization, and analysis, including CERs, Below-The-Line factors, hardware cost-to-cost factors, step functions, and learning curves for air-to-air, air-to-ground, and surface-to-air missile systems.

[1] CR-0699, "Documentation and User's Guide, Missile Module of USACEAC Standard Architecture implementation for Missile Cost Estimation", Tecolote Research, Inc. dated December 1993

The 2013 report provides tactical missile Cost Estimating Relationships (CERs) and cost factors to ODASA-CE and is, in turn, an update to the *2011 and 2002 Tactical Missile Bluebooks*. The update includes:

- Remapping the contractor cost report Work Breakdown Structures (WBSs) in the Tri-Service Missiles and Munitions Automated Cost Data Base ("Missiles ACDB") to the ODASA-CE WBS
- Breaking the air vehicle production cost into recurring and non-recurring costs
- Changing the method for estimating the missile production rate
- Changing the method for escalating costs to constant year dollars to use the midpoint of the production period rather than the year of appropriation
- Updating the lot quantity and the cumulative quantity of missiles produced prior to each production lot.

For development, this report focused on 9 tactical missiles programs—20 datapoints including those with more than one distinct model as well as separate propulsion contracts—were used in the CER regressions. This analysis only includes tactical missiles with solid fuel propulsion systems. Cruise missiles, which have turbojet engines as the primary propulsion, were not included. In addition, strategic missiles were not included.

For production, this report focused on 13 tactical missiles programs—23 datapoints including those with more than one distinct model as well as separate propulsion contracts—were used in the CER regressions.

2.2.1 DESCRIPTION OF DATASET

Datasets used in Bluebook 2002 are proprietary and are provided in appendices to the document. The dataset consists of cost data from the RDT&E and Production phases for Army, Navy, and Air Force missile systems. Data available in this study was primarily collected under previous Tecolote efforts:

- CR-0699 "Documentation and Users'Guide Missile Module of USACEAC Standard Architecture Implementation for Missile Cost Estimation",
- CR-1036 "AFCAA Missile and Munitions CER Development Study",
- CR-1057 "USACEAC Missile Production Cost Factors",

- CR-1089 "Missile and Munitions CER Development Study Production Below-The-Line Cost Research",
- CR-0896 "THAAD Cost Research",
- CR-1147 "Missile Sufficiency Review Handbook."

Additional data was collected from the Tri-Service Missile and Munitions ACDB.

For the 2013 Bluebook, the Missiles ACDB is the primary source for the cost and technical data used in deriving the CERs and factors and includes raw and normalized data that has been mapped to the standard RDT&E and Production CES. The main updates are:

- Remapping the contractor cost report Work Breakdown Structures (WBSs) in the Tri-Service Missiles and Munitions Automated Cost Data Base ("Missiles ACDB") to the ODASA-CE WBS
- Breaking the air vehicle production cost into recurring and non-recurring costs
- Changing the method for estimating the missile production rate
- Changing the method for escalating costs to constant year dollars to use the midpoint of the production period rather than the year of appropriation
- Updating the lot quantity and the cumulative quantity of missiles produced prior to each production lot.

These various updates provide greater confidence in the CERs and factors.

The database contains contractor data as reported to the government in Contractor Cost Data Reports (CCDRs).

Below is the WBS used to collect and analyze data based on MIL-STD-881. Grey highlighted elements are not included. The items in light green are not included in MIL-STD-881C WBS.

1.0 Missile/Ordnance System
1.1 Air Vehicle/Munition
1.1.1 Airframe
1.1.2 Propulsion
Guidance & Control (rollup of 1.1.3 to 1.1.7 + Other G&C)
1.1.3 Power and Distribution
1.1.4 Guidance
1.1.5 Navigation
1.1.6 Controls
1.1.7 Communications
Other G&C
1.1.8 Payload
1.1.9 Reentry System (missile only)
1.1.10 Post Boost System (missile only)
1.1.11 Ordnance Initiation Set (missile only)
1.1.12 On Board Test Equipment
1.1.13 On Board Training Equipment
1.1.14 Auxiliary Equipment
1.1.15 Air Vehicle/Munition Software
1.1.16 Air Vehicle/Munition IAT&CO
1.1.17 Other Air Vehicle/Munition

1.2 Encasement Device
1.3 Command and Launch
1.4 System Software Release
1.5 System IAT&CO
System Eng./Prog. Mgmt (rollup of 1.6, 1.7, Other SEPM)
1.6 System Engineering
1.7 Program Management
Other SEPM
1.8 Systems Test and Evaluation
1.9 Training
1.10 Data
1.11 Peculiar Support Equipment
1.12 Common Support Equipment
1.13 Operational/Site Activation
1.14 Industrial Facilities
1.15 Initial Spares and Repair Parts
1.16 Charges (G&A/Fee/COM)
1.17 Other Missile/Ordnance

MS Excel® workbooks contain the raw and normalized cost data mapped to the standard RDT&E and Production CES for the relevant programs.

The following table shows the scope of the information in the dataset for development programs. An "x" indicates data exists and was used in the analysis.

System	Model	Missile System	Prime Mission Product (PMP)	System Engineering/Program Management	Systems Test and Evaluation	Training	Data	Peculiar Support Equipment	Common Support Equipment	Operational/Site Activation	Industrial Facilities	Initial Spares and Repair Parts	Charges	Other Missile		Schedule Information	Technical/Performance Data	Government Costs
AMRAAM	AIM-120A/B	x	x	x			x		x				x				x	
AMRAAM	AIM-120A/B	x	x	x	x	x	x	x		x		x	x				x	
HARM	AGM-88A	x	x	x	x		x	x					x				x	
HELLFIRE	AGM-114L (LONGBOW)	x	x	x	x	x	x	x					x	x			x	
HELLFIRE	AGM-114L (LONGBOW)	x	x	x	x		x			x			x	x			x	
MAVERICK	AGM-65D	x	x	x	x	x	x	x									x	
MAVERICK	AGM-65D	x	x	x	x	x	x				x	x	x				x	
PATRIOT	PAC-3 MSE	x	x	x	x	x		x	x				x	x			x	
PATRIOT	PAC-3 MSE	x	x	x	x	x		x	x				x	x			x	
PATRIOT	PAC-3	x	x	x	x	x	x	x					x				x	
PATRIOT	PAC-3	x	x	x	x	x	x	x		x		x	x				x	
PATRIOT	PAC-3	x	x	x									x	x			x	
PHOENIX	AIM-54A	x	x	x	x	x	x	x				x	x	x			x	
PHOENIX	AIM-54A	x	x	x	x	x	x		x			x	x	x			x	
PHOENIX	AIM-54A	x	x	x		x	x						x				x	
SIDEWINDER	AIM-9X	x	x	x	x		x						x	x			x	
SIDEWINDER	AIM-9X	x	x	x	x	x		x		x			x	x			x	
SIDEWINDER	AIM-9X	x	x	x	x								x				x	
SPARROW	AIM-7F	x	x		x		x	x				x	x				x	
SPARROW	AIM-7F	x	x		x		x			x			x				x	

The following table breaks out production PMP showing where data has been collected and used in the analysis.

System	Model	Missile System	Prime Mission Product (PMP)	Air Vehicle	Airframe	Propulsion	Guidance & Control (inc. power, nav & comm)	Payload	On Board Test Equipment	On Board Training Equipment	Auxiliary Equipment	Air Vehicle IAT&CO	Other Air Vehicle/Munition	Encasement Device	Command and Launch	Command and Launch IAT&CO	Launch and Guidance Control (missile only)	Launcher Equipment	Auxiliary Equipment (missile only)	Command and Launch Software	Other Command and Launch
AMRAAM	AIM-120A/B	x	x	x									x								
AMRAAM	AIM-120A/B	x	x	x		x	x	x	x			x			x			x			
HARM	AGM-88A	x	x	x	x		x			x			x		x			x			x
HELLFIRE	AGM-114L (LONGBOW)	x	x	x		x	x	x	x			x			x			x			
HELLFIRE	AGM-114L (LONGBOW)	x	x	x			x														
MAVERICK	AGM-65D	x	x	x	x		x								x			x			
MAVERICK	AGM-65D	x	x	x			x					x									
PATRIOT	PAC-3 MSE	x	x	x	x	x	x	x	x		x	x		x	x			x		x	
PATRIOT	PAC-3 MSE	x	x	x	x	x	x	x	x		x	x		x	x			x		x	
PATRIOT	PAC-3	x	x	x		x	x				x	x	x	x	x		x				
PATRIOT	PAC-3	x	x	x	x	x	x	x	x		x	x		x	x	x		x	x	x	
PATRIOT	PAC-3	x	x	x	x	x	x	x	x		x	x	x	x							
PHOENIX	AIM-54A	x	x	x	x	x	x		x	x											
PHOENIX	AIM-54A	x	x	x	x	x	x														
PHOENIX	AIM-54A	x	x	x	x	x	x		x												
SIDEWINDER	AIM-9X	x	x	x			x														
SIDEWINDER	AIM-9X	x	x	x			x					x	x		x			x			
SIDEWINDER	AIM-9X	x	x	x	x		x		x												
SPARROW	AIM-7F	x	x	x	x	x	x														
SPARROW	AIM-7F	x	x	x	x		x														

O&S costs are not included in this study.

2.2.2 DESCRIPTION OF CERS

The independent variables in Bluebook 2002 were Length, Impulse, Diameter, Range, Weight, Volume, and Power of the various subsystems along with stratifying variables for air-launched and ground-launched configurations.

Bluebook 2002 concludes by stating the results presented in this study provide a reasonable, historically-based set of selected cost-to-cost factors, Learning Curve slopes (with and without Rate), and CERs for a small selected set of hardware elements.

The table below portrays the missiles and associated cost data used in the development of CERs and cost improvement curves (no cost improvement curves for development).

	Air Vehicle	Airframe	Propulsion	G&C	Payload	Total Cost*	Development
AMRAAM (AIM-120A-C)	x		x	x	x	x	x
Phoenix (AIM-54A)	x	x		x		x	x
Phoenix (AIM-54C)	x	x		x		x	
Phoenix (AIM 54A/CMK47)			x				
Sidewinder (AIM-9L)				x			
Sidewinder (AIM-9M)				x			
Sidewinder (AIM-9L/9M)			x				
Sidewinder (AIM-9X)	x		x	x		x	x
Sparrow (AIM-7F)	x			x		x	x
Sparrow (AIM /RIM-7M)	x			x		x	
Sparrow (AIM-7(MK58))			x				
ATACMS (MGM-140A)	x	x	x	x	x	x	
Patriot (MIM-104A)						x	x
Patriot (PAC-3)							x
Stinger (FIM-92C)	x		x	x		x	
HARM (AGM-88A/B)	x	x		x	x	x	x
HARM (AGM-88A)			x				
Hellfire (AGM-114L)	x		x	x	x	x	x
Maverick (AGM-65A)					x		
Maverick (AGM-65D)	x			x		x	x
MLRS (M-26)			x		x		
MLRS/GMLRS (M-30/M-31)	x	x	x	x	x	x	
Javelin (FGM-148A)	x		x	x	x	x	

* Total Cost = Air Vehicle + Below-the-line

Propulsion only contracts (4)

Thirteen tactical missile systems—21 including those with more than one distinct model—were used in the CER regressions. This analysis only includes tactical missiles with solid fuel propulsion systems. Cruise missiles, which have turbojet engines as the primary propulsion, were not included. In addition, strategic missiles were not included.

The following CERs and factors are contained in the 2013 Bluebook:

DEVELOPMENT:

- Production Recurring Hardware to Development Prototype Step-Up Factors
- Development Engineering Factors
  - As a function of Prototype cost
  - Includes Producibility, Engineering & Planning (PEP) and Tooling
- Development Below-the-Line Factors
  - Five main factors - SEPM, STE, Data, TSE, and ISRP as a function of Total Air Vehicle development (development engineering + prototype)
  - Other Below-the-Line Factors
- Development Charges Factors
  - G&A, Fee, COM, and Other Charges

PRODUCTION:

- Recurring Production Hardware CERs and Factors
  - Air Vehicle
  - Four major subsystem CERs: Airframe, Propulsion, Guidance & Control (G&C) and Payload
  - Air Vehicle Integration, Assembly and Test (IA&T) Factor
  - Other Air Vehicle Factor
- Non-recurring Air Vehicle Production CERs
- Production Below-the-Line Factors
  - Five main factors - Systems Engineering/Program Management (SEPM), System Test & Evaluation (STE), Data, Total Support Equipment (TSE) (Peculiar + Common), and Initial Spares & Repair Parts (ISRP) as a function of Total Air Vehicle production

  - Other Below-the-Line Factors
- Production Charges Factors
  - G&A, Fee, Cost-Of-Money (COM), and Other Charges
- Total Production Cost CERs
  - Sum of Air Vehicle and five main Below-the-Line costs
- The Recurring Production Hardware CERs were regressed using three approaches:
  - 1,000th Unit Cost (U1000) CERs
    - Learning curves regressed first.
    - Then, U1000 costs for a number of missiles regressed.
    - Composite learning curve slope developed
  - Unit-as-an-Independent-Variable (UAIV) CERs
    - A one-step approach using all missile lots
    - CERs include a quantity term
  - Unit-as-an-Independent-Variable (UAIV) CERs with production rate
    - A one-step approach using all missile lots
    - CERs include a quantity term and a production rate term

Ten appendices containing proprietary information are provided as separate Microsoft Excel files. These appendices provide detailed data, analyses and regressions. An eleventh appendix provides a tactical missile cost model for estimating development and production cost for a tactical missile based on technical and programmatic inputs.

2.2.3 STRENGTHS AND WEAKNESSES

The strength of Bluebook 2002 is the expanded dataset used for the study is significantly improved over the dataset used in the 1993 study and addressed most of the standard CES elements. It includes several more recent systems and systems from not only the Army but also from the Air Force and the Navy. The limited number of hardware CERs presented in this study have coefficients for the independent variables that appear reasonable, and generally have improved goodness-of-fit statistics over what was shown in the 1993 study.

The stated caution in Bluebook 2002 was that influences such as unique acquisition strategies, exotic materials, or innovative manufacturing practices, may diminish the utility of these results and these "non-historical" potential cost drivers would need to be evaluated on a case-by-case basis.

The strengths of the 2013 Bluebook is include an expanded data set, production recurring and non-recurring cost breakouts, and the use of a better methodology for escalating costs to constant year dollars, performance based CERs, and below the line cost factors for tactical missiles using MIL-STD-881 C.

2.3 "TEST AND EVALUATION TRENDS AND COSTS FOR AIRCRAFT AND GUIDED WEAPONS", RAND FOR PROJECT AIR FORCE, 2004 (RAND 2004)

RAND 2004 examined Test and Evaluation costs for fixed-wing aircraft and guided weapons programs. It examined the effects of changes in the test and evaluation process used to evaluate military aircraft and air-launched guided weapons during their development programs. The comments here-in relate to the missile portion of the study.

The purpose of the RAND 2004 project was to not only improve the tools used to estimate the costs of future weapon systems, but also on how recent technical, management, and government policy changes affect cost. The authors provided several conclusions in that regard. A cost-related conclusion is their recommendation that Government cost data be consistently accumulated and reported, just as contractor data is today. The project scope involved the following four tasks:

- Analyzing the nature of current T&E costs for aircraft, tactical missile, and guided munition systems and the trends likely to affect these costs in the immediate future
- Identifying key cost drivers
- Collecting, normalizing, and documenting representative data
- Developing a set of practical, documented methodologies formaking high-level T&E estimates.

2.3.1 DESCRIPTION OF DATASET

RAND 2004 was limited to the Systems Test and Evaluation cost element. Data was drawn from a number of sources during the course of the study. Analysis was limited to recent Air Force and Navy fixed-wing aircraft, tactical missile, and guided munition programs. Because the purpose of the study was to examine current test practices, the focus was generally on programs that had completed development within the past ten years or, in a few cases, slightly earlier. Older data were used for trend analysis and, where appropriate, to augment more-recent data in developing relationships. For contractor costs, CCDRs were generally used. Government costs from the cognizant program office or from the test organizations involved were also collected when available.

The handbook divides ST&E into five main elements:

- Development T&E (DT&E)
- Operational T&E
- Mock-ups
- T&E support
- Test facilities.

The RAND 2004 dataset is proprietary. TR-114-AF is a limited-distribution supplement to this report containing proprietary cost data for the programs described. Inquiries regarding the supplement should be directed to the Office of the Technical Director, Air Force Cost Analysis Agency.

The following table lists the sources from which contractor and government costs were obtained for guided-weapons.

Missile	Contractor Costs	CCDR/CPR	Progam Office Records	Government Costs	Progam Office Records	Test Activity Records
AMRAAM FSD		x	x		x	x
AMRAAM Ph 1			x		x	x
AMRAAM Ph 2			x		x	x
AMRAAM Ph 3			x		x	x
AIM-9X		x	x		x	x
JASSM		x	x		x	
JDAM		x				x
JSOW		x	x		x	x
SFW		x			x	x
SLAM-ER		x			x	
WCMD			x		x	

O&S costs are not included in this study.

2.3.2 DESCRIPTION OF CERS

A preferred and alternative CER were developed for Missile ST&E using contractor development cost (less ST&E) and number of test launches for the preferred CER , and number of test launches and phase duration for the alternative CER.

2.3.3 STRENGTHS AND WEAKNESSES

The primary strength of the RAND 2004 dataset is that it contains a number of observations consisting of eight guided missiles from both the Air Force and the Navy. The inclusion of Army guided missile programs in the dataset, assuming ST&E data was available, would potentially benefit the study.

Program office cost data was advantageous because these costs would include all expenditures of program funding, regardless of executing activity. The disadvantage is that

these costs are not consistently collected or retained. Information from test activities is generally more detailed but may exclude funding and effort on the program at another test activity.

2.4 TN-0202 "COST IMPROVEMENT SLOPES FOR MISSILE ACQUISITION PROGRAMS", FOR MDA, 2002 (MDA 2002)

The purpose of this technical notice is to provide analysts with information that assists in developing cost improvement curves for missile systems and methodologies for applying them in Missile Defense Agency (MDA) cost estimates. This technical notice provides results from historical data for the following areas:

- Selecting Unit Theory cost improvement curves,
- Selecting Cumulative Average Unit Cost improvement curves,
- Using rate adjusted cost improvement curves,
- Modeling Prototype Manufacturing costs and transition to Production,
- Using a single curve or independent curves for missile components, and
- Selecting cost improvement curves from groups of like systems.

2.4.1 DESCRIPTION OF DATASET

The data used in this study were taken from Contractor Cost Data Reports (CCDRs) for 21 missile system manufacturing efforts. The missile systems were selected based on availability of a complete history of the contractors' costs and include prototype and production units. The normalization process provided a fully priced manufacturing cost by missile component (guidance, control & electronics (GCE), airframe & propulsion (AP), warhead (WH), and total cost (TC) but does not include non-recurring costs, costs of equipment not included on the missile (canisters, launch equipment, off-board guidance), and costs incidental to manufacturing. The data is proprietary and is controlled by MDA. Below is a table of the missile systems used in the analysis.

System	Model	Contractor	Mission Area	Developing Service
AMRAAM	AIM-120	Raytheon	Air to Air	Air Force
ALCM	AGM-86A	Boeing	Air to Surface	Navy
AMRAAM	AIM-120	Hughes	Air to Air	Air Force
ATACM	MGM-140	LTV	Surface to Surface	Army
HARM	AGM-88A/B	TI	Air to Surface	Navy
Harpoon	UGM-84	MD	Surface to Surface	Navy
Maverick	AGM-65A/B	Hughes	Air to Surface	Air Force
Maverick	AGM-65F	Raytheon	Air to Surface	Air Force
Patriot	MIM-104A	Raytheon	Surface to Air	Army
Phoenix	AIM-54A	Hughes	Air to Air	Navy
Phoenix	AIM-54C	Hughes	Air to Air	Navy
Sidewinder	AIM-9M	Ford	Air to Air	Navy
Sidewinder	AIM-9M	Raytheon	Air to Air	Navy
Sidewinder	AIM-9L	Ford	Air to Air	Navy
Sidewinder	AIM-9L	Raytheon	Air to Air	Navy
SMII	RIM-66C	GD	Surface to Air	Navy
Sparrow	AIM/RIM-7M	Raytheon	Air to Air	Navy
Sparrow	AIM-7F	Raytheon	Air to Air	Navy
Stinger	FIM-92A RMP	GD	Surface to Air	Army
Stinger	FIM-92A	GD	Surface to Air	Army
Trident I	UGM-96A	LM	Surface to Surface	Navy

O&S costs are not included in this study.

2.4.2 DESCRIPTION OF CERS

For each missile system, a Unit Theory (UT), Cumulative Average Unit Cost Theory (CAUC), and rate adjusted (RATE) cost improvement model was developed for GCE, AP and WH components and for the missile TC. For the group models, 5%, median, and 95% confidence levels are also provided.

Also included are Engineering and Manufacturing Development transition to Production Cost Improvement Models. This analysis includes continuous and reset cost improvement curves with step factors by mission area.

2.4.3 STRENGTHS AND WEAKNESSES

The strength of dataset is that includes 21 different missiles with multiple lots. Better results are obtained when the database is stratified by type of mission which often dictate size and complexity of the missile. However, when doing so, the number of data points for each mission is greatly reduced.

2.5 CR-1229 "SYSTEM DEVELOPMENT & DEMONSTRATION PHASE DEVELOPMENT ENGINEERING COST METHODOLOGY", TECOLOTE RESEARCH, INC. FOR ODASA-CE, 2005 (SDD 2005)

The goal of SDD 2005 was to develop a report and methodologies to estimate the costs of Development Engineering. One of the motivations behind this study was the implication that the new evolutionary acquisition process may make many of the assumptions underlying existing cost estimating relationships and models obsolete.

2.5.1 DESCRIPTION OF DATASET

SDD 2005's datasets were proprietary and are separate from the report. The datasets were comprised of Missile, Radar, Launcher, C4ISR, Test Equipment, UAV, and Aviation systems. The source data included Cost Analysis Briefs (CAB) and their Life Cycle Cost Estimates (LCCEs) as well as conventional contractor cost reports.

The document's cover cites Office of the Assistant Secretary of the Army for Cost and Economics (attn: SFFM-CA-CR Mr. Jean Duval) as the point of contact. SDD 2005 was limited to the Development Engineering cost element. One hundred and two (102) data points containing Development Engineering cost data were obtained. Data was available in three forms: monthly, annual, and static. Twenty-five (25) of the data points contained monthly data; twenty-one (21) contained annual data; and fifty-six (56) contained un-phased data. Eighty-seven of those had useful information pertaining to duration and milestone dates and sixty-eight (68) had information pertaining to prototype quantity. Further,

milestone information for another eleven systems are tabulated though their Development Engineering cost data was not available.

Production and O&S costs are not included in this study.

2.5.2 DESCRIPTION OF CERS

The relationship studied in SDD 2005 was that development engineering cost is comprised of two parts: discrete and continuous. Discrete effort can be expressed as a function of the peak burn rate (expressed as expenditure rate in dollars per month) and the length of time from the beginning of the increment until the design confidence point is reached (core duration expressed in months). Similarly, the continuous effort can be expressed as a function of the sustaining level of effort (expressed as flat burn rate in dollars per month) and the total duration (expressed in months). Symbolically:

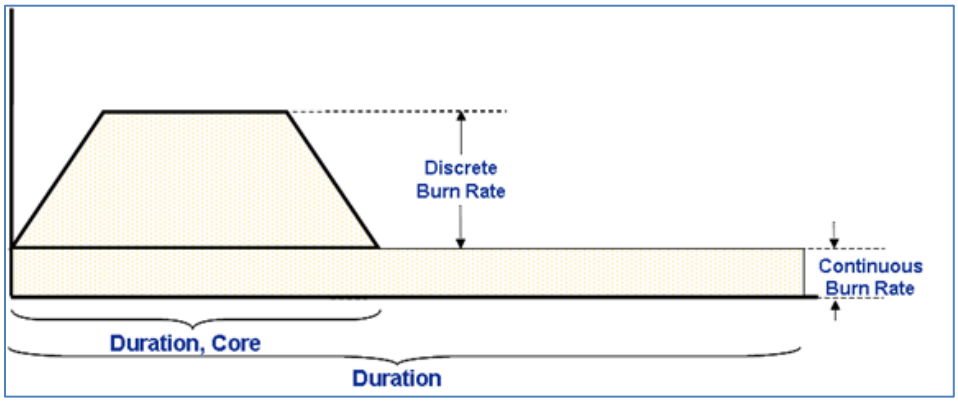
DevEng = Discrete Effort + Continuous Effort

DevEng = *f*(Peak Burn Rate, Core Duration) + *f*(Flat Burn Rate, Duration)

And further, each of the burn rates is a function of the overall system size or complexity.

Peak Burn Rate = *f*(size)

Flat Burn Rate = *f*(size) or *f*(Peak Burn Rate)



2.5.3 STRENGTHS AND WEAKNESSES

Though weighted heavily with missile systems, the strength of the SDD 2005 dataset is that many commodities are included. Also, several of the systems contained monthly data. The

dataset also included some ACAT II and ACAT III programs. In addition, the resulting statistical fits were respectable and yielded CERs that utilized schedule as a cost driver.

2.6 "SYSTEMS ENGINEERING AND PROGRAM MANAGEMENT TRENDS AND COSTS FOR AIRCRAFT AND GUIDED WEAPONS", RAND FOR PROJECT AIR FORCE, 2006 (RAND 2006)

This study the analyses what are termed "below-the-line" costs. Below-the-line costs include costs for such items as system test and evaluation, data, special test equipment and tooling, training, operational site activation, industrial facilities, initial spares and repair parts, and systems engineering and program management. These costs are not directly associated with the development or the production of the hardware end item. RAND 2006 examined Systems Engineering/Program Management costs for fixed-wing aircraft and guided weapons programs. This report specifically focused on techniques that can be used to estimate SE/PM costs. It also described various functions within SE/PM and investigated possible cost drivers of SE/PM. The missile portion of the report is described here-in.

2.6.1 DESCRIPTION OF DATASET

To develop SE/PM cost estimating methods, historical data was collected from a variety of government cost reports and internal contractor accounting reports on programs from the 1960s to today. Primary data sources were:

- Defense Cost and Resource Center;
- Air Force Cost Analysis Agency (AFCA) database developed in the late 1990s; and
- CCDR costs reported in the August 2000 Tri-Service Missiles and Munitions Database.

The data included historical costs, the schedule of major events in the program, and technical information from several missile programs structured in MIL-HDBK-881 format. Datasets are proprietary and not available to the reviewer. The datasets were made up of guided weapons systems (Navy and Air Force). The below tables contains the data that was collected for missile systems including program phases and sources of data.

Program Name		Phase	CCDR /CPR	Contractor Progam Data
Phoenix	**AIM-54A**	FSED	x	
Phoenix	**AIM-54C**	FSED	x	
Sparrow	**AIM/RIM-7M**	FSED	x	
Sparrow	**AIM/RIM-7P**	FSED	x	
AAAM	**AIM-155**	FSED	x	
AMRAAM	**AIM-120**	FSED	x	
AMRAAM	**AIM-120**	FSED 2nd Source	x	
AMRAAM	**AIM-120 P3I Phase I**	EMD P3I		x
AMRAAM	**AIM-120 P3I Phase II**	EMD P3I		x
AMRAAM	**AIM-120 P3I Phase III**	EMD P3I		x
Sidewinder	**AIM-9R**	FSED	x	
Sidewinder	**AIM-9X**	D&V	x	
Sidewinder	**AIM-9X**	EMD	x	
SRAM	**AGM-69A**	FSED	x	
SRAM II	**AGM-131A/B**	FSD	x	
Maverick	**AGM-65A**	FSED	x	
Maverick	**AGM-65D**	FSED	x	
Maverick	**AGM-65C**	FSED	x	
Harpoon	**AGM-84A**	Design and Weapons Development	x	
Harpoon	**AGM-84H**	EMD	x	
HARM	**AGM-88A, Sub Phase I**	FSED	x	
HARM	**AGM-88A, Sub Phase**	FSED	x	
HARM	**AGM-88A, Sub Phase**	FSED	x	
ALCM	**AGM-86A**	FSED	x	
ALCM	**AGM-86B**	FSD	x	
Tacit Rainbow	**AGM/RGM-136**	FSED	x	
ACM	**AGM-129A/B**	FSED	x	
	AGM-130	FSED	x	
SFW	**CBU-97/B**	FSED	x	
JSOW	**AGM-154A**	EMD	x	
JSOW	**AGM-154B**	EMD	x	
JSOW	**AGM-154C**	EMD	x	
JDAM	**GBU-31**	EMD (Phase	x	
JASSM	**AGM-158**	EMD	x	
Tomahawk	**BGM-109**	FSD	x	
SLAM-ER	**R/UGM-109E**	EMD	x	

NOTES: P3I = pre-planned product improvement
D&V = demonstration and validation.

The cost information for the relevant programs is provided in a supplementary RAND Corporation report (TR-311-AF), which is not available to the general public.

O&S costs are not included in this study.

2.6.2 DESCRIPTION OF CERS

CERs were developed in RAND 2006 for Missile RD&TE and Production phases. RAND 2006 examined duration, weight, cross-section area, diameter, and weight as candidate cost drivers. Four Cost Estimating Relationships were recommended.

- For guided weapons programs, SE/PM development cost was found to be related to the overall development cost of the program (less the cost of SE/PM). The CER fit the data reasonably well, but there was still quite a large amount of variation in the data.
- The guided weapon production data showed much more consistency (similar to a traditional learning-curve shape), which allowed the comparison of weapon production SE/PM unit costs to the overall weapon unit cost, lot midpoint, and the ratio of the lot quantity to the maximum production lot size. The CER fit the data reasonably well, but as with the rest of the CERs, showed a large variance.

2.6.3 STRENGTH AND WEAKNESSES

Strengths of the RAND 2006 is that it contains a large number of observations and the CERs fit the data reasonably well. Standard errors and the coefficient of variation are provided for the CERs developed. These metrics can be used in uncertainty analyses. The weakness of this study include the guided missile dataset does not include Army programs, and the CERs have a wide variability.

This report deals only with SE and PM costs from the prime weapons system contractor (or contractor team) during the course of a contract. SE and PM costs also occur at the subcontractor level and within the government, which require consideration when developing life-cycle cost estimates. However, due to limitations in the availability of data, these costs are not analyzed in this report. Also, the definitions used by various organizations for SE/PM vary.

2.7 CR-1501/1 "COST RISK AND UNCERTAINTY ANALYSIS METRICS MANUAL (CRUAMM) INCLUDING A MISSILE APPENDIX", TECOLOTE RESEARCH, INC. FOR AFCAA, 2011 (CRUAMM 2011)

The purpose of the CRUAMM 2011 metrics manual was to provide the analyst with a source for uncertainty distributions by commodity in the absence of better information. This manual provides guidance on the appropriate shape and size of uncertainty distributions by commodity and at various levels within a typical cost model for that commodity. Several commodities are addressed in the study including missiles.

2.7.1 DESCRIPTION OF DATASET

The CRUAMM 2011 Missile dataset was comprised of missiles and air-launched munition systems from the MSSRH 2011 study. The dataset is described in Section 2.1.1.

Data used in MSSRH 2011 is comprised of RDT&E and production data from Army, Navy, and Air Force missile systems. These studies addressed the full cost element structure (CES) of the development and production phases.

The dataset includes 66 development data points and 207 production lots. Additionally the work breakdown structure was modified to increase the granularity of hardware subsystems.

The MSSRH dataset is proprietary and is managed by AFCAA and contains raw and normalized data that has been mapped to the standard RDT&E and Production CESs. The primary types of data are CCDRs and CPRs largely from the ACDB's Tri-Service Missile Database.

O&S costs are not included in this study.

2.7.2 DESCRIPTION OF CERS

The relationship studied in CRUAMM 2011 was the dispersion of CER residuals. The results of this study are unitized distributions that can be multiplied by a point estimate to obtain a cost element's uncertainty when modeled as follows (causing the uncertainty to scale with the point estimate):

Cost Element $_{\text{Uncertainty}}$ = Your Methodology * Unitized Distribution

The unitized distributions are provided in tables as exemplified by the following:

		Numerator		Denominator		Sample	Fitted
Dataset	Count	Label	Range	Label	Range	CV	CV
SEPM	28	SEPM$	9223 - 582640	PMP$	9864 - 1190909	0.419	0.408
Systems Engineering	24	SE$	4704 - 455032	PMP$	9864 - 1154853	0.385	0.376
Program Management	22	PM$	1956 - 127607	PMP$	9864 - 1154853	0.711	0.670
Other SEPM	14	OSEPM$	9 - 480973	PMP$	25866 - 1190909	1.331	1.401
System Test and Evaluation	27	STE$	1153 - 451385	PMP$	9864 - 1190909	0.811	0.931
Training	20	Training$	4 - 67599	PMP$	61479 - 1423376	1.687	3.076
Data	24	Data$	14 - 41361	PMP$	9864 - 1190909	1.331	1.621
Support Equipment	22	SptEq$	47 - 189777	PMP$	36293 - 1423376	0.758	0.705
Initial Spares and Repair Parts	5	InitSp$	1341 - 16926	PMP$	61479 - 1423376	0.873	1.083
Tooling	12	Tooling$	2 - 214340	PMP$	9864 - 1154853	1.159	1.168

	My Point Estimate is the:		
Dataset	Mean	Median	Mode
SEPM	Triangular (0.3310, 0.5194, 2.1496)	Triangular (0.3551, 0.5571, 2.3057)	Triangular (0.6373, 1.0000, 4.1385)
Systems Engineering	Triangular (0.1115, 0.9397, 1.9489)	Triangular (0.1130, 0.9529, 1.9761)	Triangular (0.1186, 1.0000, 2.0739)
Program Management	Triangular (0.0000, 0.1056, 2.8944)	Triangular (0.0000, 0.1192, 3.2669)	Triangular (0.0000, 1.0000, 27.3995)
Other SEPM	Beta (0.0010, 4.0550, 0.1370, 0.4189)	Beta (0.0076, 29.7267, 0.1370, 0.4189)	Beta (, , 0.1370, 0.4189)
System Test and Evaluation	Lognormal (1.0000, 0.9307)	Lognormal (1.3661, 1.2713)	Lognormal (2.5493, 2.3725)
Training	Lognormal (1.0000, 3.0758)	Lognormal (3.2343, 9.9479)	Lognormal (33.8319, 104.0598)
Data	Lognormal (1.0000, 1.6205)	Lognormal (1.9042, 3.0858)	Lognormal (6.9048, 11.1894)
Support Equipment	Triangular (0.0000, 0.0049, 2.9951)	Triangular (0.0000, 0.0056, 3.4053)	Triangular (0.0000, 1.0000, 606.8504)
Initial Spares and Repair Parts	Lognormal (1.0000, 1.0826)	Lognormal (1.4738, 1.5955)	Lognormal (3.2010, 3.4653)
Tooling	Beta (0.0003, 5.8845, 0.4381, 2.1404)	Beta (0.0006, 11.0498, 0.4381, 2.1404)	Beta (, , 0.4381, 2.1404)

Unitized distributions are included for the following:

- Missile RDT&E Cost Elelment Percentage of PMP Cost
- Missile Nonrecurring Cost as a Percentage of Recurring Cost
- Missile Nonrecurring Cost per Pound
- Missile Nonrecurring Cost per UC100
- Missile RDT&E Burn Rate (Cost per Month)
- Missile Production Cost Element Percentage of PMP
- Missile Cost Improvement Curve Slopes
- Missile Unit Cost per Pound
- Missile Schedule Durations

- Missile Schedule Growth

2.7.3 STRENGTH AND WEAKNESSES

The strength of CRUAMM 2011 is its comprehensive approach to measuring distributions so that objective uncertainty could be applied to cost and schedule uncertainty analysis. Also, a significant strength of MSSRH, and therefore CRUAMM 2011 since it uses the same dataset, is that the dataset includes 66 development and 207 production data points and includes data from all three services. Most of the standard Cost Element Structure elements are represented in the dataset.

The weakness of CRUAMM 2011 flow from MSSRH 2011 and preponderance of factor relationships rather than fitted CERs.

2.8 "CONTRACTS PRICE & SCHEDULE DATABASE", TECHNOMICS, DODCAS BRIEFING, 2014 (CONTRACTS 2014)

Contracts 2014 is an update to Contracts 2012 adding 10 programs and 472 contracts to the dataset. Contracts 2014 is a comprehensive automated tool that contains contract and contract modification information, including descriptions, down to the CLIN level.

It provides insight into "reasons for changes over time" which could be valuable for conducting root cause analysis. It also provides means for measuring growth over time and provides a cross-check with other data sources.

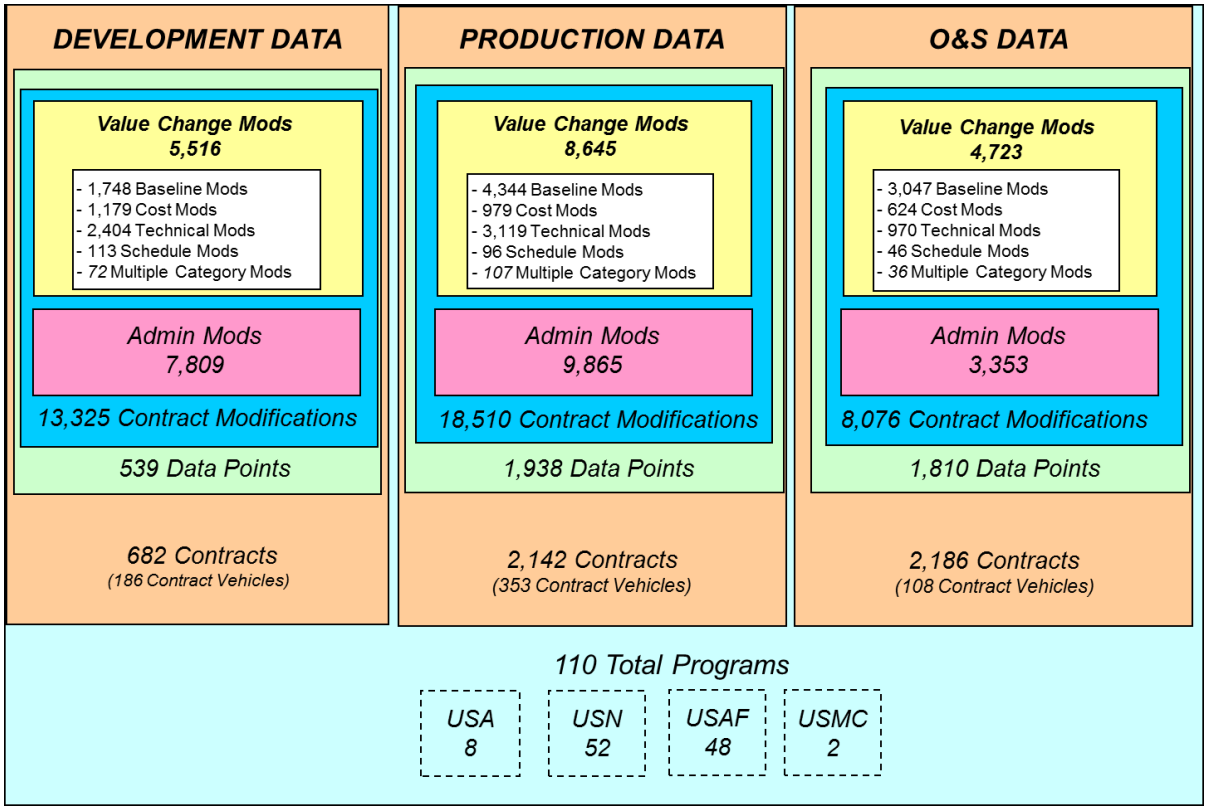
2.8.1 DESCRIPTION OF DATASET

The Contracts 2014 dataset consists of contract data across many commodities (Aircraft, Decoys, Electronics, Engine, Laser, Missiles, Munitions, Non-Lethal, Space, Targets/Drones, UAV). It provides cost/price/fee data, period of performance information, quantities, enables the visibility of contract price changes to the CLIN and contract modification level.

The Army, Navy, and Air Force all have systems included in the database. The majority of the data is on Navy and Air Force programs.

The database was structured by CLIN data rather than traditional cost elements structure. The data is contained in an MS Access® database tool and is managed by the NCCA and AFCAA sponsors.

The Contracts 2014 dataset is depicted in the following figure:



The missile progams included in the dataset include:

Service	Army	Air Force	Navy
Missiles	ATACMS (MGM-140)	ACM (AGM-129)	AARGM (AGM-88E)
	JAGM	AGM-130	AWS
	JCM (AGM-169)	ALCM/CALCM (AGM-86A-D)	ESSM (RIM-162)
	PAC-3 (MIM-104F)	AMRAAM (AIM-120)	HARM (AGM-88)
	Patriot (MIM-104A-D)	CHAMP	Harpoon/SLAM-ER (AGM-84)
	SLAMRAAM	DRADM	JSOW (AGM – 154A, A/C, C)
		HAVE NAP (AGM-142)	RAM BLK 0,1,2 (RIM-116/A/B)
		JASSM (AGM-158)	RATTLRS
		Maverick (AGM-65)	Sea Sparrow
			Sidewinder (AIM-9)
			SM-1,2,3,4,6
			Sparrow (AIM-7)
			Standard Missile
			Tomahawk Block III & IV (BGM-109)
			VLA Missile (RUR-5 ASROC)

The Contracts 2014 material illustrates how the tool developed can be used to develop cost growth factors, estimating factors, and learning curves. It does not present cost estimating methodologies per se, or address cost drivers directly. Potential applications of the tool include:

- Development of cost estimates
  - Cost growth metrics
  - Data completeness
  - Data fidelity
  - Cross check
- Program assessments/Root Cause Analyses

- Support special studies
- Contract price data source

O&S costs are not included in this study.

2.8.2 DESCRIPTION OF CERS

The data was used to populate an interactive database that could be used to develop cost growth factors, estimating factors, learning curves, as well as histogram and time series charts. The database does not contain any CERs.

2.8.3 STRENGTHS AND WEAKNESSES

The strengths of Contracts 2014 are the relatively large number of observations (30 programs) and the comprehensive dataset that includes contract CLIN information and provides insight into program's cost. CLIN costs, particularly fixed-price CLINs, can be absent in conventional contractor cost reports. CLINs can also depict engineering changes then cannot otherwise be visible within the WBS of the contactor's cost reports.

A potential weakness of the Contracts 2014 database is the relative sparse number of Army programs. However, for missile systems, Army programs are well represented.

3: ASSESSMENT

Cost estimating methodologies in this body of literature ranged from fitted equations for CERs to simple ratio relationships. Weight, in particular, is an ever-present technical parameter followed by configuration-type stratifying parameters such as guidance type. Duration was a common programmatic parameter in these studies.

Typically these databases are comprised of data from Contractor Cost Reports and direct collection from the cognizant program office or from the organizations involved. Chronologically speaking, each study absorbed the data used in the preceding study. The Government costs were generally not addressed in these studies with the exception of the RAND study on ST&E. The sponsor in each case retains ownership and is the gatekeeper for subsequent releases of the data. These were typically one-time data collection efforts.

Each of the study's work breakdown structures (WBS) generally followed MIL-STD-881's Appendix C. In each instance they complied with the version of 881 in force at the time. The Army-sponsored studies further followed the Army Cost Handbook. The following three tables summarize the elements addressed in the studies reviewed.

Development	RAND 2004	SDD 2005	RAND 2006	MSSRH 2011	CRUAMM 2011	Bluebook 2013	Contracts 2014 (1)
Air Vehicle		x		x		x	x
Systems Engineering			x	x	x		
Program Management			x	x			
Systems Test and Evaluation	x			x			
Training				x			
Data				x			
Peculiar Support Equipment				x			
Common Support Equipment							
Operational/Site Activation							
Industrial Facilities				x	x		
Initial Spares and Repair Parts							

(1) Contracts and CLINs, some datapoints may go lower

Production	RAND 2004	SDD 2005	RAND 2006	MSSRH 2011	CRUAMM 2011	Bluebook 2013	Contracts 2014 (1)
Air Vehicle				x	x	x	x
Systems Engineering			x	x	x	x	
Program Management			x	x	x	x	
Systems Test and Evaluation	x			x	x	x	
Training				x	x	x	
Data				x	x	x	
Peculiar Support Equipment				x	x	x	
Common Support Equipment						x	
Operational/Site Activation				x	x	x	
Industrial Facilities						x	
Initial Spares and Repair Parts				x	x	x	

(1) Contracts and CLINs, some datapoints may go lower

AIR Vehicle Production	RAND 2004	SDD 2005	RAND 2006	MSSRH 2011	CRUAMM 2011	Bluebook 2013	Contracts 2014 (1)
Air Vehicle				x	x	x	x
Airframe				x	x	x	
Propulsion				x	x	x	
Power and Distribution						x	
Guidance				x	x	x	
Navigation					x	x	
Controls				x	x	x	
Communications					x	x	
Payload				x	x	x	
Reentry System							
Post Boost System							
Ordnance Initiation Set							
On Board Test Equipment						x	
On Board Training Equipment						x	
Auxiliary Equipment						x	
Air Vehicle Software						x	
Air Vehicle IAT&Co				x	x	x	

(1) Contracts and CLINs, some datapoints may go lower

The strengths of these studies are the completeness of the dataset with respect to the population of available tactical missiles. The weakness of these studies is the unfortunate lack of estimating relationships at lower levels of detail. This is particularly notable because the salient distinguishing characteristic between missiles is often subsystems such as the seeker. This is the case not only between programs but between models within a missile family. In addition, improved capture of government program management and test & evaluation costs is needed. None of the studies address the O&S phase of a missile system.

4: NEEDS AND FUTURE RESEARCH

4.1 GRANULARITY

The methodologies in the body of work reviewed require technical and programmatic data. Typically the limiting factor for each study's methodologies is sparse technical data. The secondary limiting factor is data granularity in both cost and technical data. Therefore, one of the greatest needs for future research is additional technical data - particularly at the lower levels and deeper WBS levels of hardware cost data.

4.2 GOVERNMENT COSTS

The datasets reviewed contain excellent breadth in contractor costs. As a consequence, the resulting CERs and cost-to-cost factors calculate only contractor costs. Estimating the cost of Government costs for an LCCE is often accomplished with less parametric rigor. The two largest segments of Government cost for acquisition phases are ST&E and SEPM.

As noted in RAND 2004, the collection and reporting of Government ST&E varies across organizations and there is no central repository of government testing cost data at the Service or Command levels. It is possible to expand the dataset to include the past decade's experience and add Army systems to enlarge the dataset and improve results. Data collection should prioritize and selectively engage specific missile program offices. Data collected could include labor costs, range time cost, facilities, equipment rental, test quantity, test schedules, etc. If test cost detail could be compiled, it could be useful for analogy estimates, cross-checking a primary methodology, or bounding the test cost estimate in an uncertainty analysis. The disparity in the collection, reporting, and retention of test data will make this a challenging undertaking. Especially useful will be stratifying the data by phase of testing such as Developmental Test (DT); Initial Operational Test & Evaluation (IOT&E); and the increasingly common Limited User Test (LUT).

Another area of improvement is Government SEPM costs. Government SEPM is usually estimated using a known or planned quantity of government and support contractor personnel

at a program office multiplied by duration and rate. A collection of program office data to include number of personnel, number of other government agency personnel, and average rates would be immensely useful for head-count analogies. This data would include all the functional organizations (business management, logistics management, technical management, for example) within the program related specifically to the system of interest. The data collected could be useful as a primary estimating methodology, cross-checks, or uncertainty bounds.

4.3 UNCERTAINTY

In future methodology development efforts, characterizing each resulting methodology in terms that support the current state-of-the-art in uncertainty analysis would be a plus. Some standard minimum requirements on fit statistics (standard error, CV, and a prediction interval at the center of the data) should be determined and enforced by agencies producing cost estimating methodologies. Ideally, each future CER will also be accompanied with an uncertainty distribution fitted to the CER's residuals as was done in CRUAMM 2011. Another aspect of the current state-of-the-art in uncertainty is duration. Since program schedules are always uncertain and cost is sensitive to schedule, the inclusion of duration in CER's cost driving parameters should be encouraged when appropriate.

4.4 O&S COSTS

Given that most contemporary missiles are certified rounds encased in a launch tube or container, the absence of O&S costs noted in this review are somewhat small relative to missile acquisition costs or to other commodities' O&S costs. Nonetheless, aging and surveillance activity, storage, and eventual disposal are non-trivial efforts and usable datasets of actual costs would be valuable to analysts estimating the O&S cost of missile systems.

4.5 ACAT II AND ACAT III PROGAMS

The Government's emphasis on capturing contractor cost reports on major weapon system acquisition is successful. However, smaller programs and upgrade efforts may fall below cost reporting requirement thresholds and not get captured with the same rigor. This

shortcoming affects the missile and munitions arena more so than other commodities because the sheer number of smaller-scale munitions, bomb kits, and seeker upgrade programs. Capturing ACAT II and ACAT III programs in a central repository would increase the availability and accessibility of valuable data on small programs.

5: FURTHER READING

1. *The Joint Agency Cost Schedule Risk and Uncertainty Handbook, 27 January 2014* presents the current state-of-the art in uncertainty analysis. This document sheds further light on the observations made in this review regarding the need for Missile System uncertainty matrics associated with each point estimate methodology

2. *A Case Study Using Cost Data from the DCARC Repository, DoD Cost Analysis Symposium (DoDCAS), February 2012* sheds further light on the MSSRH 2011 by illustrating mapping and the MSSRH's associated Data Viewer and the data's roots in DCARC data,