Improving Software Estimating Relations for Army Software Sustainment Data

DASA-CE

Presented to

ICEAA

May 2020

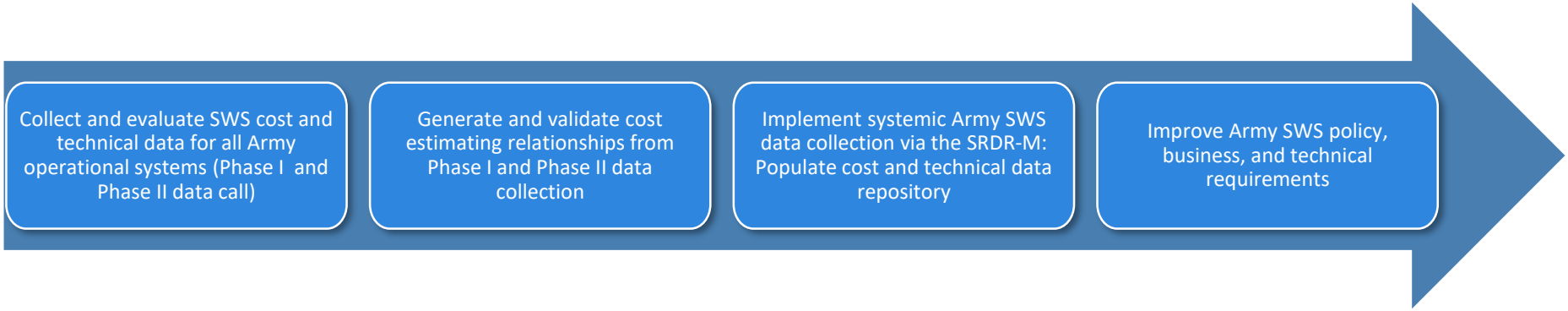
Presentation Overview

- Objectives and Strategy
- Summary of Accomplishments
- Army Software Sustainment WBS
- Data Demographics
- New Cost Estimating Relationships (CER)
  - Annualized Capability Release CERs
  - Causal Relationship Driven CER
- Next Steps

SWS Initiative Objective and Strategy

Accurately estimate Army system Software Sustainment (SWS) costs to:

- Effectively estimate and justify software and system life cycle costs
- Objectively evaluate Army system software sustainment execution costs
- Inform and optimize the allocation of available sustainment resources across the Army



Effective software sustainment cost estimation is the basis for Army system software life cycle cost management

Summary of Accomplishments

- Established Software Sustainment Data Collection Mechanisms
  - Army Software Data Collection Questionnaire
  - Software Sustainment WBS Used to Collect Sustainment Costs
  - Annual Data Collection
- Created Comprehensive Software Sustainment Data Repository
  - 192 Systems
  - 700 Capability Releases
  - 300 IAVA Releases
  - 3,200 records on software license data
- Established Robust Foundation for Software Sustainment Fact-Based Decisions
  - Allocations of Costs by WBS Elements
  - Continue to improve Software Sustainment Cost Estimating Relationships
- Data and Analysis Results provided to DoD Community

DASA-CE SWS WBS

Software Sustainment

System Specific

1.0 Software Change Product

1.1 Capability Changes
- Change requirements
- Change development
- B/L Integration & Test
- IV&V

1.2 IAVA Changes

System Specific

2.0 Project Management

Planning
Execution management
Configuration management
Resource & team management
Contracting management
Measurement - reporting

System/Non-System Specific

3.0 Software Licenses

License - Right to Use
- COTS/GOTS
- NDI
- Open Source
- Other

License - Maintenance

System Specific

4.0 Certification & Accreditation

Security
Safety
Networthiness
Airworthiness

System/Non-System Specific

5.0 System Facilities

Hardware
- Software development assets/workstations
- System integration & test facilities
- Test equipment - tools

Facility Operations

System Specific

6.0 Sustaining Engineering

6.1 Help desk
6.2 Hosting
6.3 Engineering and User Support
- Test Support
- Software Delivery
- Technical Studies
- Training

System/Non-System Specific

7.0 Field Software Eng.

On-Site technical assistance
Problem Troubleshooting
S/W Installation
Operational Assistance
On-site Training

Non-System Specific

8.0 Other

Operations
Organization management
Personnel management
Financial management
Information management
Process management
Change management

Version 5.0

Army Software Sustainment Definition

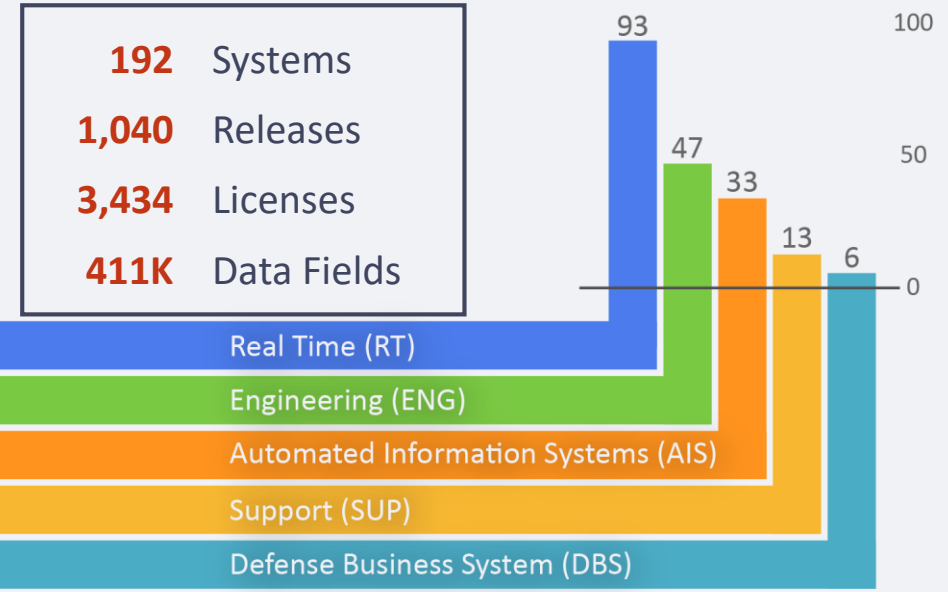
- Software sustainment (SWS) includes all software change activities and products associated with modifying a software system after a software release has been provided to an external party
- The release is the primary SWS change product - a composite of one or more changes - it can be either a formal release or an engineering release
- SWS includes software enhancements, software maintenance, and cybersecurity updates
- Software maintenance includes defect repair, rehosting, adaptations, updates, and reconfiguration
- SWS may be funded by multiple funding sources
- Costs include both Fixed and Variable costs accrued at both the system and organizational levels
- Costs include both organic (government) and contractor resources

Data Demographics

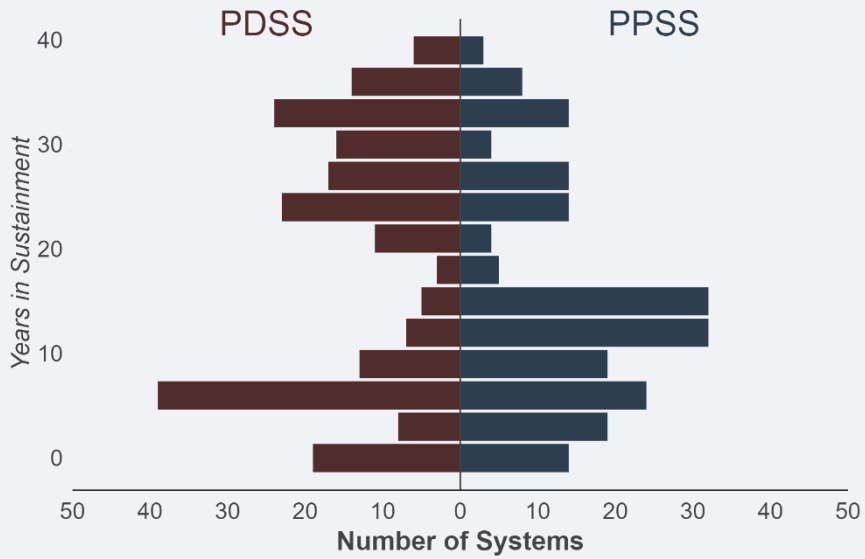
Overview

192	Systems
1,040	Releases
3,434	Licenses
411K	Data Fields

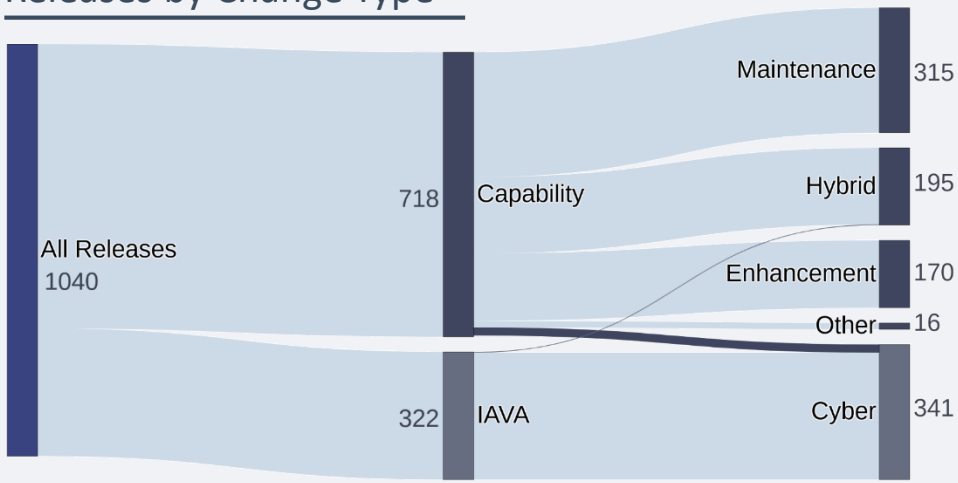
Systems by Super Domain



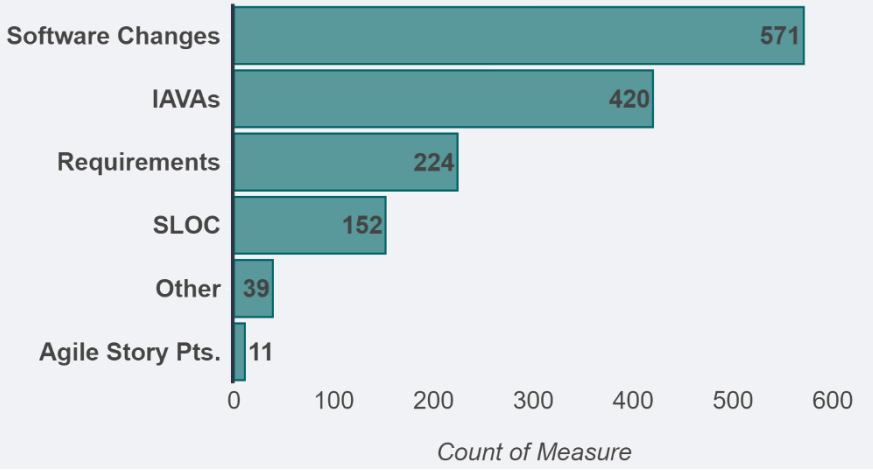
Distribution of System Age



Releases by Change Type



Releases by Size Measure

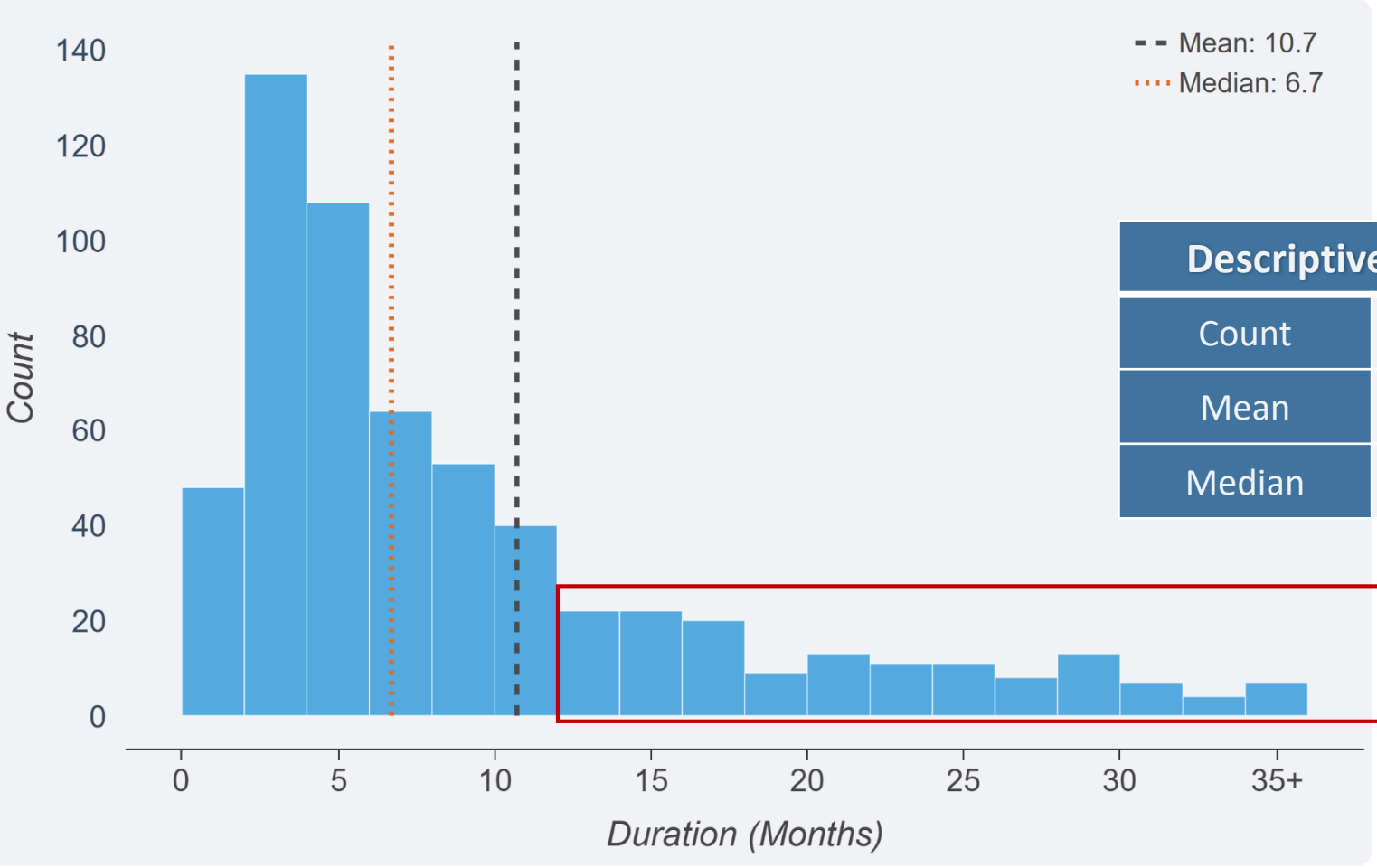


Annualized Capability Release CERs

Annualizing Data

- Data for WBS elements 2 to 8 were collected for each Fiscal Year (FY)
- Capability release data was collected by release
- Start and end dates for a significant number of releases spanned multiple years (next slide)
- Multi-year release data was proportioned into corresponding FYs creating annualized release data
- Annualized data was re-evaluated for annual CERs
- Benefits
  - Annualized data is compatible with other WBS data
  - Future data collection will be collected annually and the annualized data will be compatible
  - New CERs match annual funding cycle

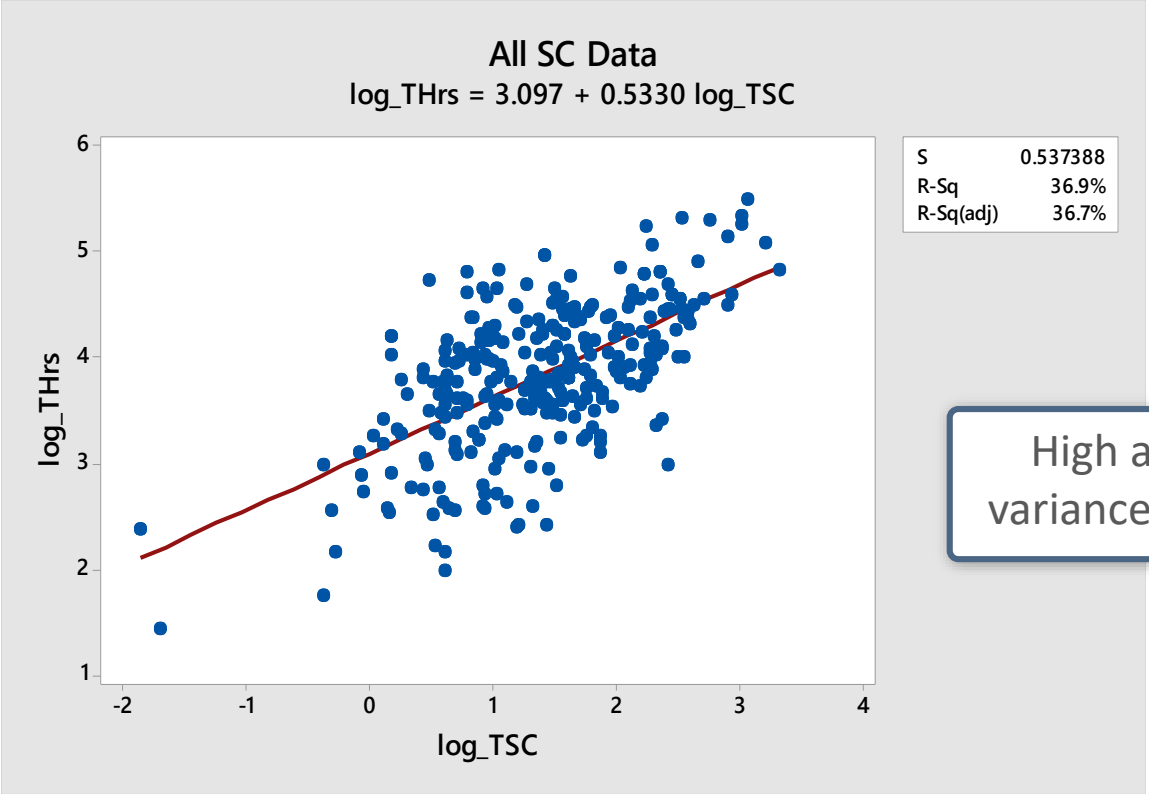
Release Duration Distribution



Descriptive Statistics	
Count	614
Mean	10.713
Median	6.702

Multi-Year Releases

All Annualized Data CER



High amount of variance in the Data

Equation

THrs = 1,249 * TSC$^{0.53}$

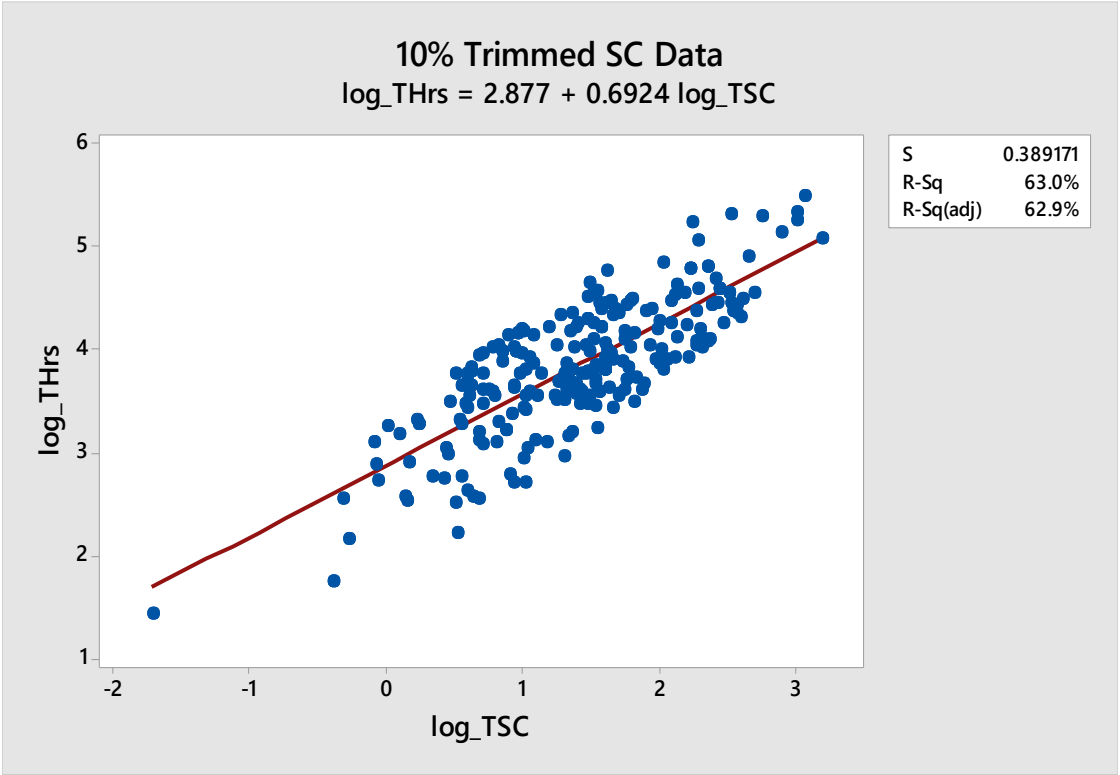
R-Squared	36.9%
Adj. R-Squared	36.7%
Observations	306

Variable	Coef.	Std Err	T-Value	P-Value
Constant	3.0967	0.063	49.45	0.000
Log(SC)	0.533	0.0399	13.34	0.000

CER Analysis Approach

- Two strategies were employed to reduce variability in the data
  - The upper and lower 10% of the data was trimmed from the dataset - Trimming was based on unit cost (total release hours / #software changes)
  - Meta-data was used to segment the release data
    - Super Domains
      - Real-Time (RT)
      - Engineering (ENG)
      - Automated Information Systems (AIS)
      - Support (SUP)
    - Acquisition Category (ACAT) Level
    - Commodities (13)

Strategy 1: Trimmed Data CER*



Equation

THrs = 754 * TSC$^{0.69}$

R-Squared	63.0%
Adj. R-Squared	62.9%
Observations	244

Variable	Coef.	Std Err	T-Value	P-Value
Constant	2.877	0.0538	53.45	0.000
Log(SC)	0.6924	0.0341	20.32	0.000

* Data records trimmed by 10%

Assumptions

- Used 10% upper & lower trimmed data
- Removed records with:
  - Defense Business Systems (DBS) super domain
  - Hour data outliers or missing data
  - Records with no dependent variable, e.g., SW Change (SC) counts
- Aggregated Acquisition Category (ACAT) Levels
  - ACAT I
  - ACAT II
  - ACAT III+ consists of ACAT III, ACAT IV and non-Programs of Record
- Both Dependent and Independent variables were transformed using $\log_{10}$
  - Zeros were represented with 0.1
- All categorical variables were represented as dummy variables (0,1)
- Adjusted R^2 was used for model performance comparisons

Annualized CERs vs Previous CERs

Annualized Data Model		Conditions	Obs	Adj R^2	Prev Obs	Prev R^2
THrs = 1,249 * $(TSC)^{0.53}$		All data	306	0.37	329	0.36
THrs = 754 * $(TSC)^{0.69}$		10% trimmed data	244	0.63	263	0.57
AIS	THrs = 459 * $(TSC)^{0.69}$	10% trimmed & Super Domains (Categorical)	244	0.63*	263	0.62
ENG	THrs = 703 * $(TSC)^{0.69}$					
RT	THrs = 869 * $(TSC)^{0.69}$					
SUP	THrs = 1,208 * $(TSC)^{0.69}$					
Aviation	THrs = 656 * $TSC^{0.71}$	10% trimmed & Commodities (Categorical)	244	0.70*	263	0.68*
Business	THrs = 348 * $TSC^{0.71}$					
C5ISR	THrs = 704 * $TSC^{0.71}$					
ChemBio	THrs = 174 * $TSC^{0.71}$					
Comms	THrs = 650 * $TSC^{0.71}$					
Fire	THrs = 724 * $TSC^{0.71}$					
Intel	THrs = 781 * $TSC^{0.71}$					
Missiles	THrs = 1,460 * $TSC^{0.71}$					
MissionCmd	THrs = 1,600 * $TSC^{0.71}$					
Network	THrs = 805 * $TSC^{0.71}$					
SATCOM	THrs = 1,484 * $TSC^{0.71}$					
Simulation	THrs = 368 * $TSC^{0.71}$					
Vehicles	THrs = 411 * $TSC^{0.71}$					
THrs = 787 * $SC\_Total^{0.90}$ / $Req\_T^{0.17}$		10% trimmed	32	**0.81**	32	**0.84**
THrs = 808 * $SC\_Total^{0.81}$ / $Req\_Imp^{0.11}$		10% trimmed	104	0.70	65	0.74

** High P-Values for one or more coefficients*

New Annualized CERs -1

Annualized Data Model		Conditions	Obs	Adj R^2
ACAT I ACAT II ACAT III+	THrs = 769 * SC_Total$^{0.68}$ THrs = 1,124 * SC_Total$^{0.68}$ THrs = 713 * SC_Total$^{0.68}$	10% trimmed & ACAT Levels (Categorical)	244	0.64*
THrs = 483 * SC_Total$^{0.80}$		10% trimmed, ACAT I	59	**0.79**
AIS ENG RT	THrs = 573 * SC_Total$^{0.79}$ THrs = 409 * SC_Total$^{0.79}$ THrs = 577 * SC_Total$^{0.79}$	10% trimmed, ACAT I & Super Domains	59	0.79*
THrs = 359 * SC_Total$^{0.90}$		10% trimmed, ACAT I & RT	35	**0.85**
THrs = 1,563 * SC_Total$^{0.40}$		10% trimmed, ACAT I & ENG	19	0.63
THrs = 2,805 * SC_Total$^{0.43}$		10% trimmed, ACAT I & AIS	5	**0.87**
THrs = 1,265 * SC_Total$^{0.65}$		10% trimmed, ACAT II	34	0.65
AIS ENG RT	THrs = 3,428 * SC_Total$^{0.62}$ THrs = 1,648 * SC_Total$^{0.62}$ THrs = 1,125 * SC_Total$^{0.62}$	10% trimmed, ACAT II & Super Domains	34	0.68*
THrs = 2,742 * SC_Total$^{0.0.34}$		10% trimmed, ACAT II & RT	18	0.05
THrs = 1,545 * SC_Total$^{0.64}$		10% trimmed, ACAT II & ENG	10	**0.84**
THrs = 794 * SC_Total$^{0.91}$		10% trimmed, ACAT II & AIS	4	0.36

New Annualized CERs -2

Annualized Data Model		Conditions	Obs	Adj R^2
THrs = 851 * SC_Total$^{0.64}$		10% trimmed, ACAT III+	151	0.55
AIS	THrs = 479 * SC_Total$^{0.65}$	10% trimmed, ACAT III+ & Super Domains	151	0.55
ENG	THrs = 951 * SC_Total$^{0.65}$			
RT	THrs = 851 * SC_Total$^{0.65}$			
SUP	THrs = 706 * SC_Total$^{0.65}$			
THrs = 1,076 * SC_Total$^{0.58}$		10% trimmed, ACAT III+ & RT	60	0.49
THrs = 583 * SC_Total$^{0.87}$		10% trimmed, ACAT III+ & ENG	49	0.58
THrs = 386 * SC_Total$^{0.73}$		10% trimmed, ACAT III+ & AIS	28	0.59
THrs = 2,673 * SC_Total$^{0.34}$		10% trimmed, ACAT III+ & SUP	17	0.33

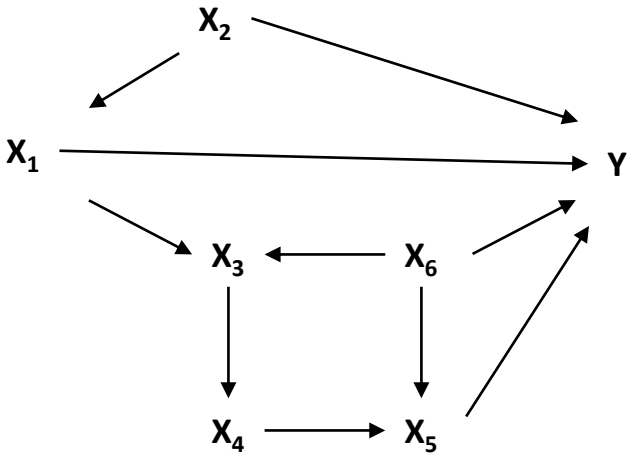
Conclusions on Annualized CERs

- The CER analysis of the annualized data is not much different in performance than CERs for the multi-year release data
- Using CERs based on annualized data makes cost estimation easier going forward because funding requests are done by fiscal year.
- Using the converted annualized data will make it possible to combine the new and old datasets.
- Previous CERs used categorical data resulting in all members in the category having the same exponent but different constants
- Changing the CER approach to sub-setting the data and allowing each CER to have its own constant and exponent provides more insight into weaker performing members of the category

Causal Relationship Driven CERs

Correlation versus Causation

- It is well known that *correlations* among factors does not necessarily mean *causation*.
  - For example, an increase in ice cream sales is correlated with shark attacks
- Because of this, regression models are often the wrong tool to use for causal search, i.e., identifying which factors affect the outcome.
- These models may use predictor variables that are influenced by variables outside the model, *confounding* variables. The model may have a good fit to the data but will not be accurate making estimates



Confounding Variable Example

- X_2 influences both X_1 and Y and X_1 influences Y. A change in X_2 will produce a change in both X_1 and Y
- X_6 influences Y as does X_5 but X_6 also influences X_5. A change in X_6 will produce a change in both X_5 and Y
- Conclusion: choose only 2 of the 4 influencing factors on Y

Causal Relationship Analysis

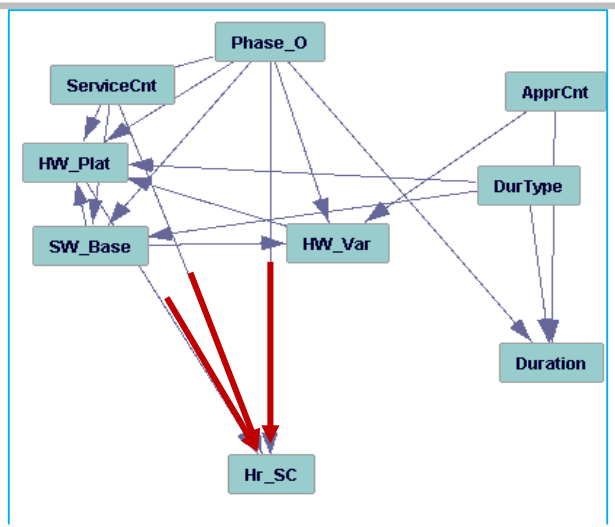
- The Army Software Maintenance Initiative collaborated with the Software Engineering Institute (SEI), Pittsburgh, PA, to investigate cause and effect relationships in collected maintenance data.
- The large number of factors in the software maintenance data make it challenging to identify which ones are useful for grouping data
- As a result of causal analysis, the data was segmented into two tiers
  - First tier was data segmented by Super Domain
  - Second tier was segmented by ACAT level within each super domain
- Unit cost (total release hours per software change) was used as the variable of interest, Y, in the analysis
- Different factors appear in different groups meaning different predictors are used in CERs
- This presentation only shows the causal relationship graphs and CERs for the Real-Time super domain and the three ACAT level releases

Causal Analysis Influencing Factors

Super Domain	ACAT I	ACAT II	ACA III+
RT	• Phase • Inter-Service Partner Count • HW Platforms	• Inter-Service Partner Count	• Hardware Variants • Maintenance Phase • Software Baseline
ENG	(None)*	• Number of Appropriations • Hardware Variants • Maintenance Phase • Inter-Service Partner Count • Software Baseline	• Duration Type • Hardware Variants • Maintenance Phase
AIS	• Inter-Service Partner Count*	(No info)	• Duration Type • Inter-Service Partner Count

** There were very few observations in two of three ACAT I datasets making casual effects harder to analyze.*

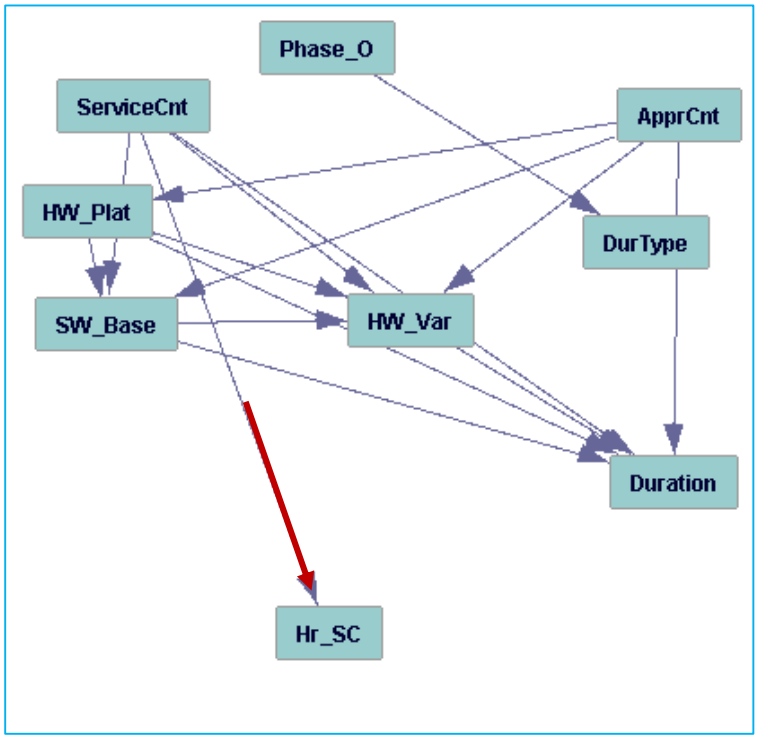
Real-Time ACAT I Releases



Data Model		Conditions	Obs	Adj R^2
ACAT I ACAT II ACAT III+	THrs = 544 * $(TSC)^{0.74}$ THrs = 544 * $(TSC)^{0.74}$ THrs = 544 * $(TSC)^{0.74}$	10% | RT | ACAT Levels	68	0.71*
THrs = 577 * $(TSC)^{0.81}$		10% | RT | ACAT I	23	0.74
THrs = 164 * $(TSC)^{1.0}$ * $ServCnt^{1.10}$		10% | RT | ACAT I | ServCnt	23	**0.84**
THrs = 91 * $(TSC)^{0.94}$ * $HW\_Plat^{0.18}$		10% | RT | ACAT I | HW_Plat	22	**0.80**
MS C MS C - FRP O&S	THrs = 260 * $(TSC)^{0.74}$ THrs = 394 * $(TSC)^{0.74}$ THrs = 787 * $(TSC)^{0.74}$	10% | RT | ACAT I | Phases (Ordinal)	23	0.71
THrs = 161 * $(TSC)^{1.00}$ * $ServCnt^{1.05}$ * $HW\_Plat^{0.0011}$		10% | RT | ServiceCnt | HW_Plat	22	0.84*

***** *High P-Values for one or more coefficients*

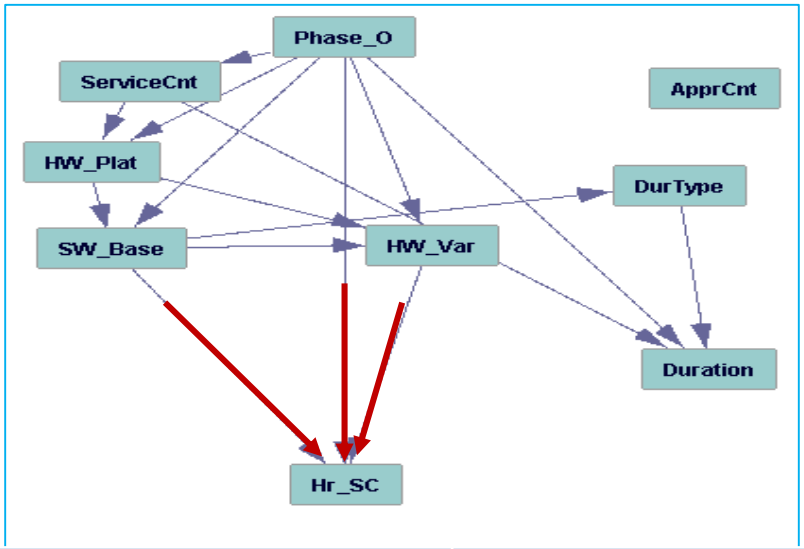
Real-Time ACAT II



Data Model		Conditions	Obs	Adj R^2
ACAT I	THrs = 544 * $(TSC)^{0.74}$	10% | RT | ACAT Levels	68	0.71*
ACAT II	THrs = 544 * $(TSC)^{0.74}$			
ACAT III+	THrs = 544 * $(TSC)^{0.74}$			
THrs = 308 * $(TSC)^{0.95}$		10% | RT | ACAT II	23	**0.75**
THrs = 287 * $(TSC)^{0.94}$ * $ServCnt^{1.86}$		10% | RT | ACAT II | ServiceCnt	23	**0.75**

***** *High P-Values for one or more coefficients*

Real-Time ACAT III+



Data Model		Conditions	Obs	Adj R^2
ACAT I ACAT II ACAT III+	THrs = 544 * $(TSC)^{0.74}$ THrs = 544 * $(TSC)^{0.74}$ THrs = 544 * $(TSC)^{0.74}$	10% | RT | ACAT Levels	68	0.71*
THrs = 467 * $(TSC)^{0.99}$		10% | RT | ACAT III+	22	0.61
THrs = 280 * $(TSC)^{1.02}$ * $SW\_Base^{0.46}$		10% | RT | ACAT III+ | SW_Base	22	0.65
THrs = 252 * $(TSC)^{1.01}$ * $HW\_Var^{0.74}$		10% | RT | ACAT III+ | HW_Var	22	0.64*
MS C - FRP MS C - LRP O&S	THrs = 272 * $(TSC)^{0.92}$ THrs = 465 * $(TSC)^{0.92}$ THrs = 776 * $(TSC)^{0.92}$	10% | RT | ACAT III+ | Phases (Ordinal)	22	0.67*
MS C - FRP MS C - LRP O&S	THrs = 138 * $(TSC)^{1.07}$ * $SW\_Base^{0.51}$ THrs = 70 * $(TSC)^{1.07}$ * $SW\_Base^{0.51}$ THrs = 328 * $(TSC)^{1.07}$ * $SW\_Base^{0.51}$	10% | RT | ACAT III+ | SW_Base | Phases (Ordinal)	22	0.67*

** High P-Values for one or more coefficients*

Conclusions on Causal-driven CERs

- Causal relationship analysis provided insight into which independent variables should be examined for predicting total release hours
- This saved a lot of random analysis time.
- The discovered relationships also suggested other relationships that could answer different information needs such as which data does not contribute to CER formulation and can be eliminated from data collection
- Segmenting data as suggested by causal analysis generally shows more CER accuracy in each segment versus trying to find a one-size-fits-all CER.
- It also highlights poor performing members in the segment that need further investigation.
- Causal analysis should proceed regression analysis to save time and eliminate confounding variables

Next Steps

- Next Steps
- Annual data collection
  - Collection of FY18 PPSS actual execution data by Army G4
  - Development of Army OSMIS data repository for data collection and storage
  - The Software Resources Data Reporting for Maintenance (SRDR-M*) closely aligns to the DASA-CE SWS WBS and data requirements
    - Moving forward, the SRDR-M will be utilized to collect SWS data from Army programs and perform analysis
- Annualized release data will continue to be analyzed for benchmarks, annual changes in software changes, and for estimating relationships with the other WBS elements
- The causal relationships will be updated using both new and old data and the CERs will be revised based on the discovered relationships

*See http://cade.osd.mil/policy/dids for more information

Contributors

Cheryl Jones

Software Measurement Analyst
US Army AFC
973-724-2644

James Doswell

Senior Operations Research Analyst
ODASA-CE
703-697-1572

Dr. Bradford Clark

Vice President
Software Metrics, Inc.
(703) 754-0115

James Judy

NISEC Division Chief
ODASA-CE
703-697-1612

Dr. Robert Charette

President
ITABHI Corporation
(540) 972-8150

Paul Janusz

Software Measurement Analysis
US Army AFC
973-724-2644

Acronyms -1

ACAT	Acquisition Category
AIS	Automated Information System super domain
BL	Software Change Backlog
BY	Base Year
C&A	Certification and Accreditation
C5ISR	Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, and Reconnaissance
CADE	Cost Assessment Data Enterprise
CER	Cost Estimating Relationship
COTS	Commercial Off The Shelf
CRED	Uncertainty Estimation Determination
CSCI	Computer Software Configuration Item
Cyber%	Percent of the release that is Cybersecurity updates
DASA-CE	Deputy Assistant to the Secretary of the Army for Cost and Economics
DBS	Defense Business System commodity
DIACAP	DoD Information Assurance Certification and Accreditation Process
DISA	Defense Information Systems Agency
DoD	US Department of Defense
DSLOC	Delivered Source Lines of Code
ECP	Engineering Change Proposal
El_Mod	External Interfaces Modified
ENG	Engineering super domain
Enh%	Percent of the release that is Enhancements to the system
EW	Electronic Warfare

Acronyms -2

FSE	Field Software Engineering
FTE	Full Time Equivalent
IAVA	Information Assurance Vulnerability Alert
IAVM	Information Assurance Vulnerability Management
ICEAA	International Cost Estimating and Analysis Association
Maint%	Percent of the release that is Maintenance changes
NVD	National Vulnerability Database
O&S	Operations and Sustainment
ODC	Other than Direct Costs
OMA	Operations and Maintenance Army funding
OPA	Other Program Army funding
OSMIS	Operation/Sustainment Management Information System
PDSS	Post-Deployment Software Support
PEO	Program Executive Office
POM	Program Objective Memorandum
PPSS	Post-Production Software Support
PTR	Problem Trouble Report

Acronyms - 3

RDT&E	Research, Development, Testing, and Evaluation
RMF	Risk Management Framework
RT	Real-Time super domain
SC	Software Changes
SEC	Software Engineering Center
SER	Schedule Estimating Relationship
SLOC	Source Lines of Code
SRDR	Software Resources Data Report
SRDR-M	Software Resources Data Report for Maintenance
STIG	Security Technical Implementation Guides
SUP	Mission Support super domain
SW	Software
SWBase	Software Baseline SLOC
SWS	Software Sustainment
TDEV	Time to Develop
THrs	Total release hours
TReqts	Total Requirements in a system
TReqts_Imp	Total Requirements Implemented in a release
TSC	Total Software Changes for a release
WBS	Work Breakdown Structure