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2018-03-27

# Agile Software Development Cost Modeling for the US DoD

Rosa, Wilson; Madachy, Ray; Clark, Bradford; Boehm, Barry

Software Engineering Institute

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<http://hdl.handle.net/10945/58515>

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# Agile Software Development Cost Modeling for the US DoD

Wilson Rosa, Naval Center for Cost Analysis

Ray Madachy, Naval Postgraduate School

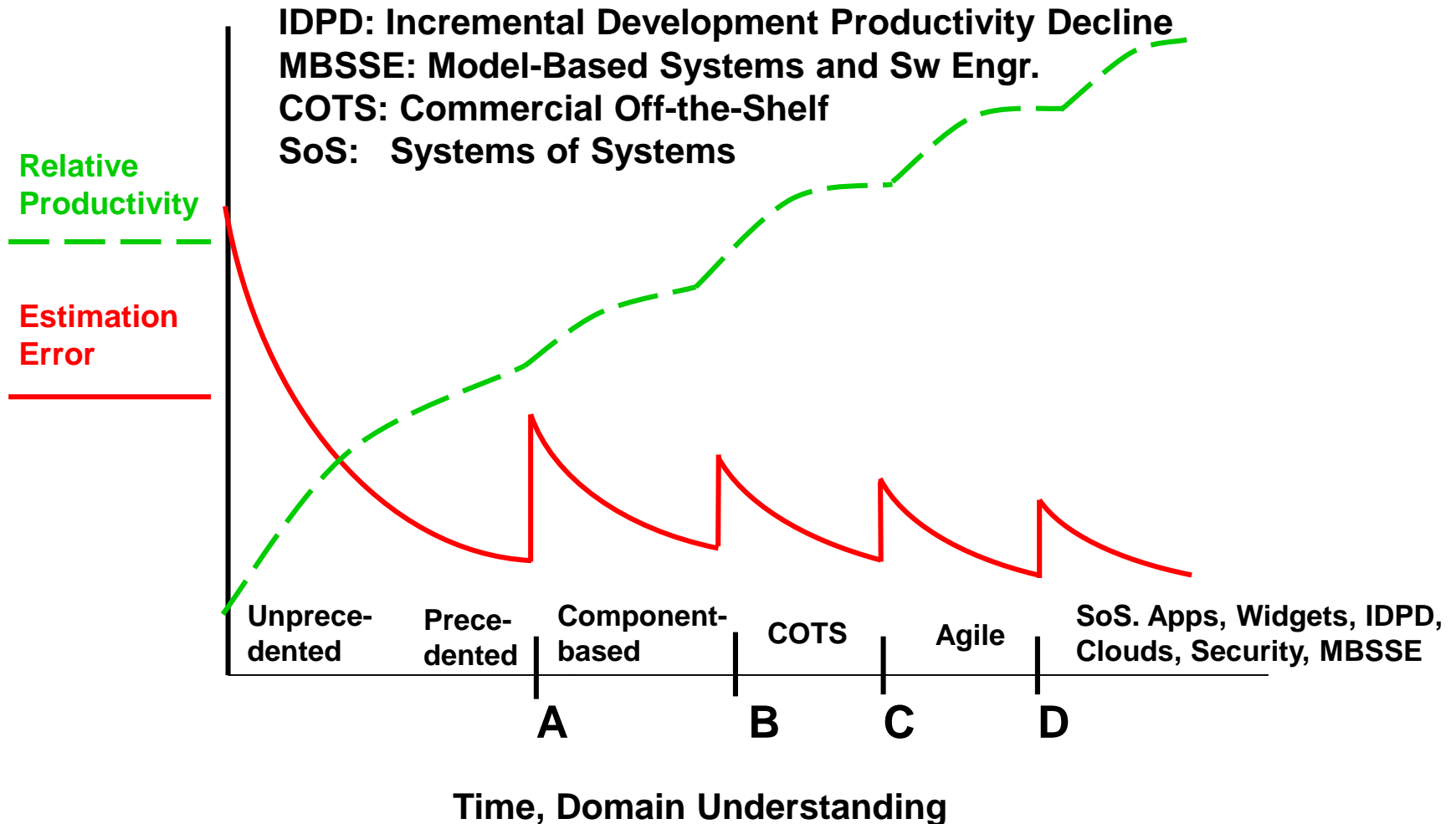
Bradford Clark, Software Metrics, Inc.

**Barry Boehm, University of Southern California**

SEI Software and Cyber Solutions Symposium

March 27, 2018

# A Short History of Software Estimation Accuracy



# Problem Statement

- In DoD, Popular Size Measures are often not available for Agile Effort Estimation at early phase
  - Function Points (FP)
  - COSMIC FP
  - Story Points
  - Source Lines of Code
- No Publicized/Empirical Agile Effort Estimation Models

- Publish Agile Effort Estimation Models for
  - Crosschecking Contractor Cost Proposals
  - Validating Independent Government Cost Estimates
- Examine the validity of using Initial Software Requirements as proxy size measure
- Develop useful cost models using early phase information
- Model calibration comparison:

<b>Model Type</b>	<b>Size</b>		<b>Cost Factors</b>		<b>Effort</b>
	Initial Estimate	Final Actual	Initial Estimates	Final Actuals	Final Actual
Early Phase	X		X		X
Traditional		X		X	X

# Outline

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- Experimental Design
- Dataset Demographics
- Productivity Benchmarks
- Agile Effort Estimation Models
- Conclusion

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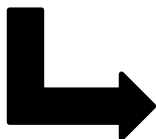
# Experimental Design

# Primary Data Collection Form

- 2011 Software Resource Data Report (SRDR) (DD Form 2630)

## SRDR Final Developer Report

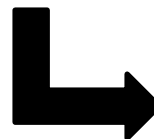
Section 3.1.1 UNCLASSIFIED				
SECURITY CLASSIFICATION				
SOFTWARE RESOURCES DATA REPORTING: FINAL DEVELOPER REPORT (SAMPLE FORMAT 3)				
Due 60 days after final software delivery and 60 days after delivery of any release or build.				
Section 3.1 REPORT CONTEXT AND DEVELOPMENT ORGANIZATION				
MAJOR PROGRAM a. NAME: Section 3.1.2		b. PHASE/MILESTONE: Section 3.1.2		
REPORTING ORGANIZATION TYPE Section 3.1.3 <input type="checkbox"/> PRIME/ASSOCIATE CONTRACTOR <input type="checkbox"/> DIRECT-REPORTING SUBCONTRACTOR <input type="checkbox"/> GOVERNMENT	NAME/ADDRESS a. REPORTING ORGANIZATION: Section 3.1.4			
		b. DIVISION: Section 3.1.4		
APPROVED PLAN NUMBER Section 3.1.5	CUSTOMER Section 3.1.6	CONTRACT TYPE Section 3.1.7		
WBS ELEMENT CODE Section 3.1.8	WBS REPORTING ELEMENT Section 3.1.8			
TYPE ACTION a. CONTRACT NO.: Section 3.1.9	c. SOLICITATION NO.: Section 3.1.9	e. TASK ORDER/DELIVERY ORDER NO.: Section 3.1.9		
b. LATEST MODIFICATION: Section 3.1.9		d. NAME: Section 3.1.9		
PERIOD OF PERFORMANCE		APPROPRIATION Section 3.1.11	SUBMISSION NUMBER Section 3.1.12	
a. START DATE (YYYYMMDD): Section 3.1.10	b. END DATE (YYYYMMDD): Section 3.1.10	RD&E	RESUBMISSION NUMBER Section 3.1.13	
		PROCUREMENT	REPORT AS OF (YYYYMMDD) Section 3.1.14	
		O&M	DATE PREPARED (YYYYMMDD) Section 3.1.15	
NAME (Last, First, Middle Initial) Section 3.1.15	Department Section 3.1.15	Telephone (Include Area Code) Section 3.1.15	EMAIL ADDRESS Section 3.1.15	
DEVELOPMENT ORGANIZATION Section 3.1.16	SOFTWARE PROCESS MATURITY Section 3.1.17	LEAD EVALUATOR Section 3.1.17		
CERTIFICATION DATE Section 3.1.17		EVALUATOR AFFILIATION Section 3.1.17		
PRECEDENTS (List up to five similar systems by the same organization or team.) Section 3.1.18				
SRDR DATA DICTIONARY FILENAME Section 3.1.19				
COMMENTS Section 3.1.20				



**Actual** Development Effort  
**Actual** Development Process

## SRDR Initial Developer Report

Section 3.1.1 UNCLASSIFIED				
SECURITY CLASSIFICATION				
SOFTWARE RESOURCES DATA REPORTING: INITIAL DEVELOPER REPORT (SAMPLE FORMAT 2)				
Due 60 days after contract award and 60 days after start of any release or build.				
Section 3.1 REPORT CONTEXT AND DEVELOPMENT ORGANIZATION				
MAJOR PROGRAM a. NAME: Section 3.1.2		b. PHASE/MILESTONE: Section 3.1.2		
REPORTING ORGANIZATION TYPE Section 3.1.3 <input type="checkbox"/> PRIME/ASSOCIATE CONTRACTOR <input type="checkbox"/> DIRECT-REPORTING SUBCONTRACTOR <input type="checkbox"/> GOVERNMENT	NAME/ADDRESS a. REPORTING ORGANIZATION: Section 3.1.4			
		b. DIVISION: Section 3.1.4		
APPROVED PLAN NUMBER Section 3.1.5	CUSTOMER Section 3.1.6	CONTRACT TYPE Section 3.1.7		
WBS ELEMENT CODE Section 3.1.8	WBS REPORTING ELEMENT Section 3.1.8			
TYPE ACTION a. CONTRACT NO.: Section 3.1.9	c. SOLICITATION NO.: Section 3.1.9	e. TASK ORDER/DELIVERY ORDER NO.: Section 3.1.9		
b. LATEST MODIFICATION: Section 3.1.9		d. NAME: Section 3.1.9		
PERIOD OF PERFORMANCE		APPROPRIATION Section 3.1.11	SUBMISSION NUMBER Section 3.1.12	
a. START DATE (YYYYMMDD): Section 3.1.10	b. END DATE (YYYYMMDD): Section 3.1.10	RD&E	RESUBMISSION NUMBER Section 3.1.13	
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SRDR DATA DICTIONARY FILENAME Section 3.1.19				
COMMENTS Section 3.1.20				



**Estimated** Functional Requirements  
**Estimated** External Interfaces  
**Estimated** Peak Staff  
Application Domain



# Population and Sample Size

Empirical data from 20 recent US DoD Agile programs:

**12** Paired SRDRs from the Cost Assessment Data Enterprise (CADE)

Each paired SRDR includes:

SRDR Initial Developer Report (**Estimates**)  
&  
SRDR Final Developer Report (**Actuals**)



<http://dcarc.cape.osd.mil/Default.aspx>

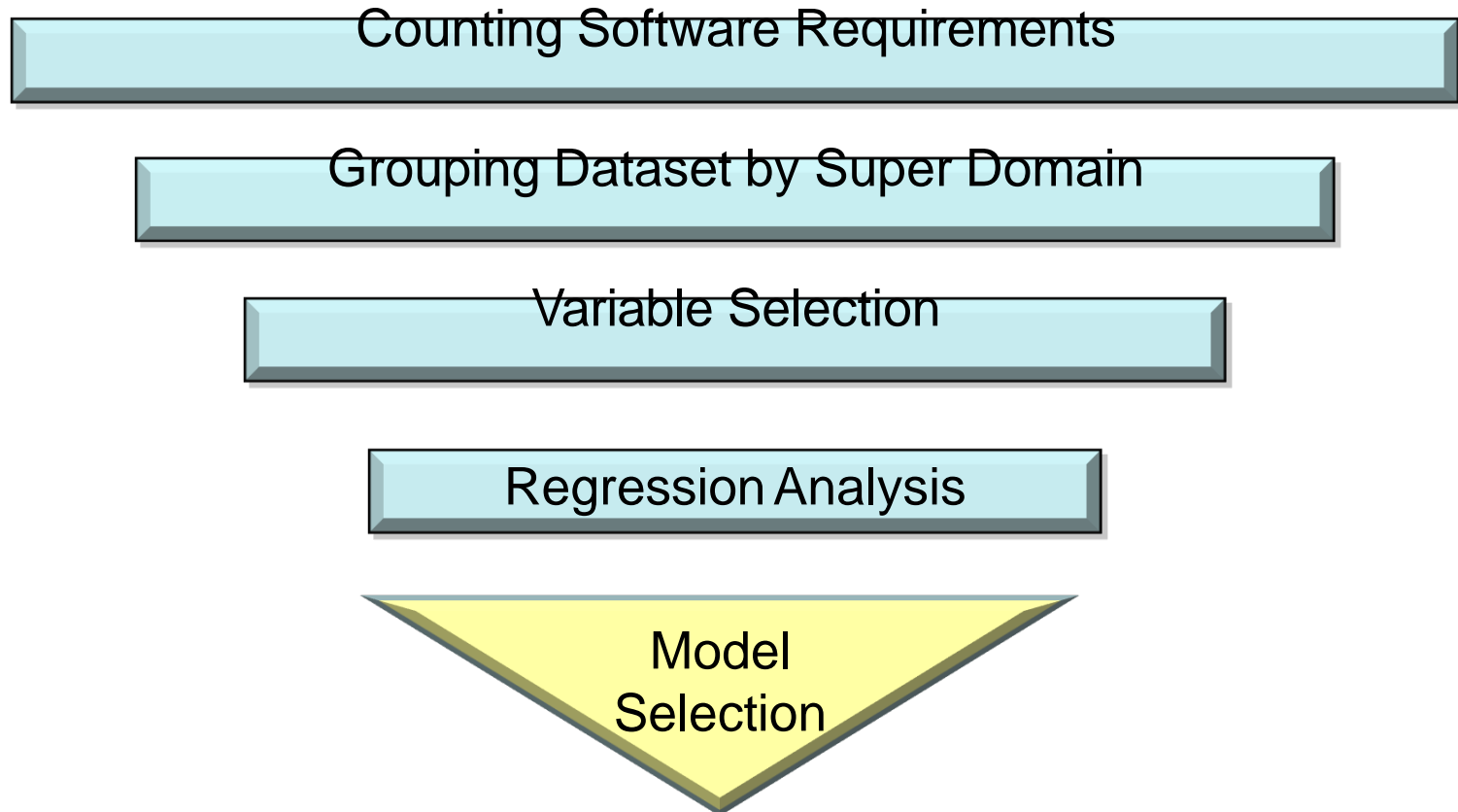
- +** 4 additional SRDRs from CADE (SRDR Final only)
- +** 4 Agile projects from proprietary source

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- =** **20** Agile projects analyzed in this study

# Data Normalization and Analysis Workflow

- Dataset normalized to “account for sizing units, application complexity, and content so they are consistent for comparisons” (source: GAO)



# Counting Software Requirements

**Initial** Functional Requirements\*



**Initial** External Interfaces\*



Initial Software Requirements

“shall” statements contained in the baseline Software Requirements Specification (SRS)

“ shall” statements contained in the baseline Interface Requirements Specifications (IRS)

SRDR **Initial** Report

SRDR **Initial** Report

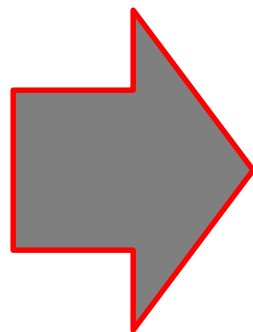
S  
O  
U  
R  
C  
E

\*Typically available before contract award  
\*Definitions align with IEEE std. 830-1998

# Grouping Dataset by Super Domain

- 1) Dataset initially mapped into 17 Application Domains\*
- 2) Then into 4 complexity groups called Super Domains

Application Domain
Software Tools
Training
Enterprise Information System
Enterprise Services
Custom AIS Software
Mission Planning
Test, Measurement, and Diagnostic Equipment
Scientific & Simulation
Process Control
System Software
Command & Control, Communications
Real Time Embedded
Vehicle Control/Payload
Signal Processing, Microcode & Firmware



Super Domain
Mission Support (SUPP)
Automated Information System (AIS)
Engineering (ENG)
Real Time (RTE)

# Grouping Dataset by Super Domain

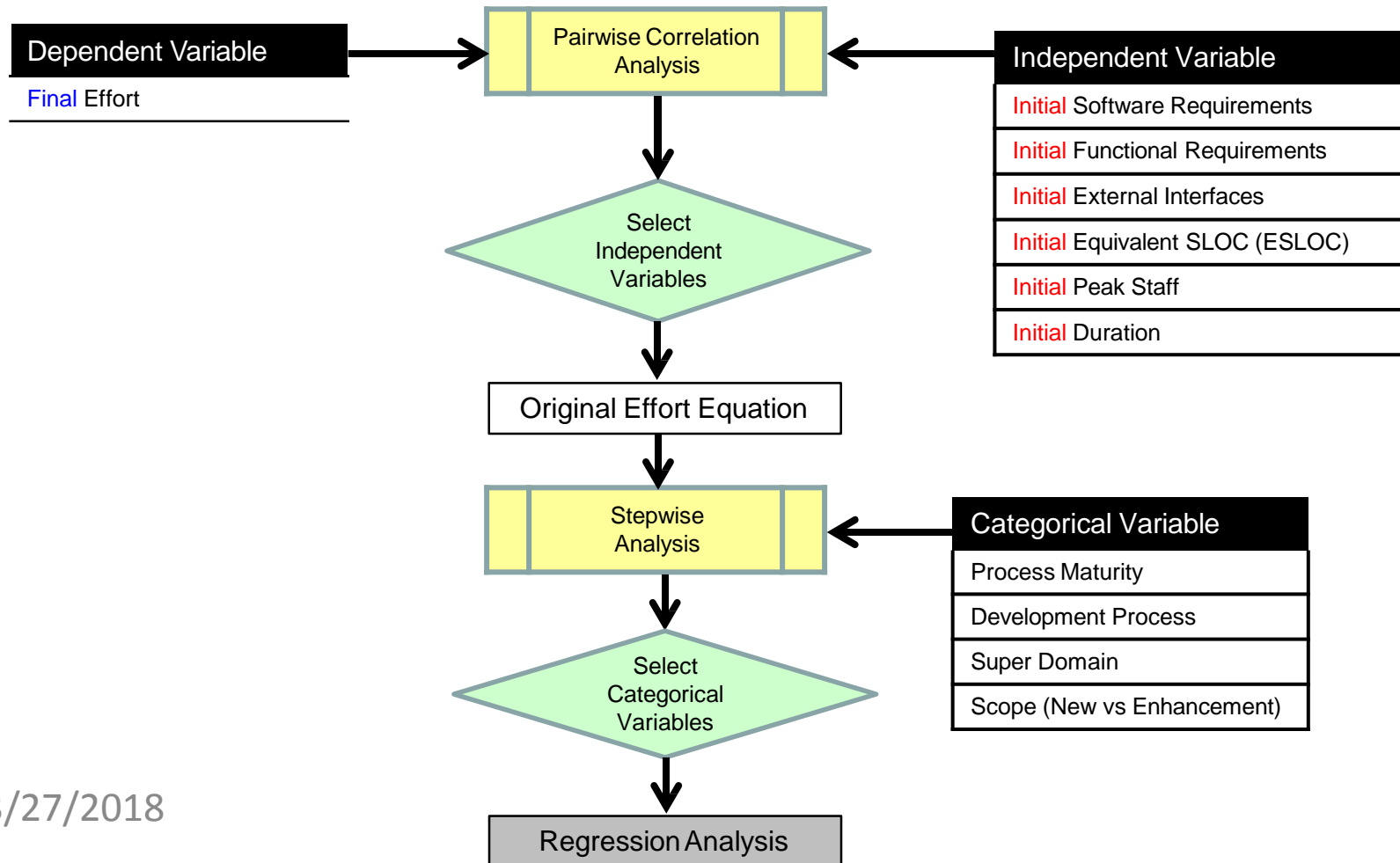
## Super Domains

	Support	AIS	Engineering	Real Time	TOTAL
Aircraft	2	0	4	0	6
Business	1	3	0	0	4
C4I	0	1	3	5	9
Missile	0	0	0	1	1
	3	4	7	6	20

Top 2 Operating Environments à C4I and Aircraft

# Variable Selection

- 1) Pairwise Correlation to select Independent Variables
- 2) Stepwise Analysis to select Categorical Variables



# Model Selection

## § Model Selection Based on P-Value, lowest MMRE and CV

Measure	Symbol	Description
Coefficient of Variation	CV	Percentage expression of the standard error compared to the mean of dependent variable. A relative measure allowing direct comparison among models.
P-value	$\alpha$	Level of statistical significance established through the coefficient alpha ( $p \leq \alpha$ ).
Variance Inflation Factor	VIF	Indicates whether multi-collinearity (correlation among predictors) is present in multiple regression analysis.
Coefficient of Determination	$R^2$	The Coefficient of Determination shows how much variation in dependent variable is explained by the regression equation.
Mean Magnitude of Relative Error	MMRE	Low MMRE is an indication of high accuracy. MMRE is defined as the sample mean (M) of the magnitude relative error (MME). MME is the absolute value of the difference between Actual and Estimated effort divided by the Actual effort, $(A - E) / A$

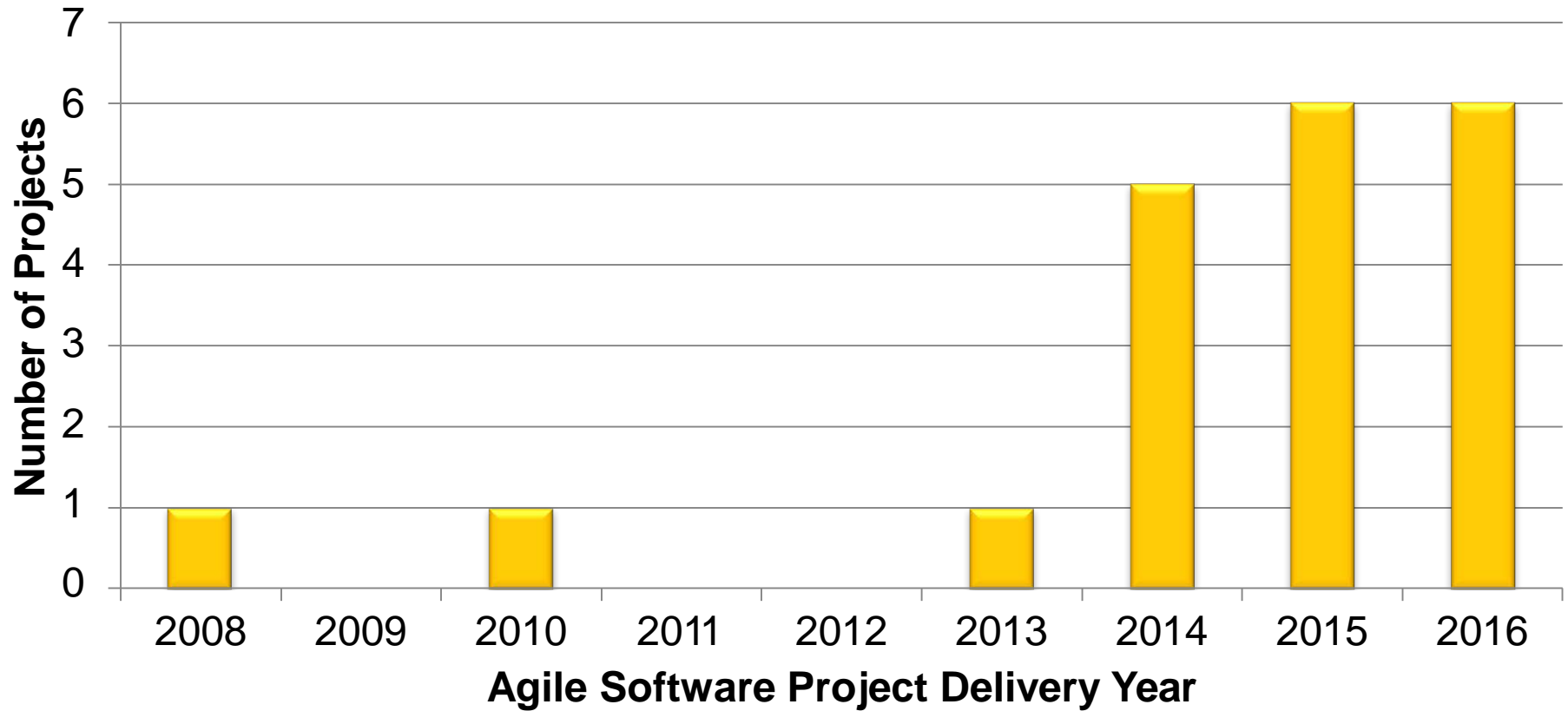
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# Dataset Demographics

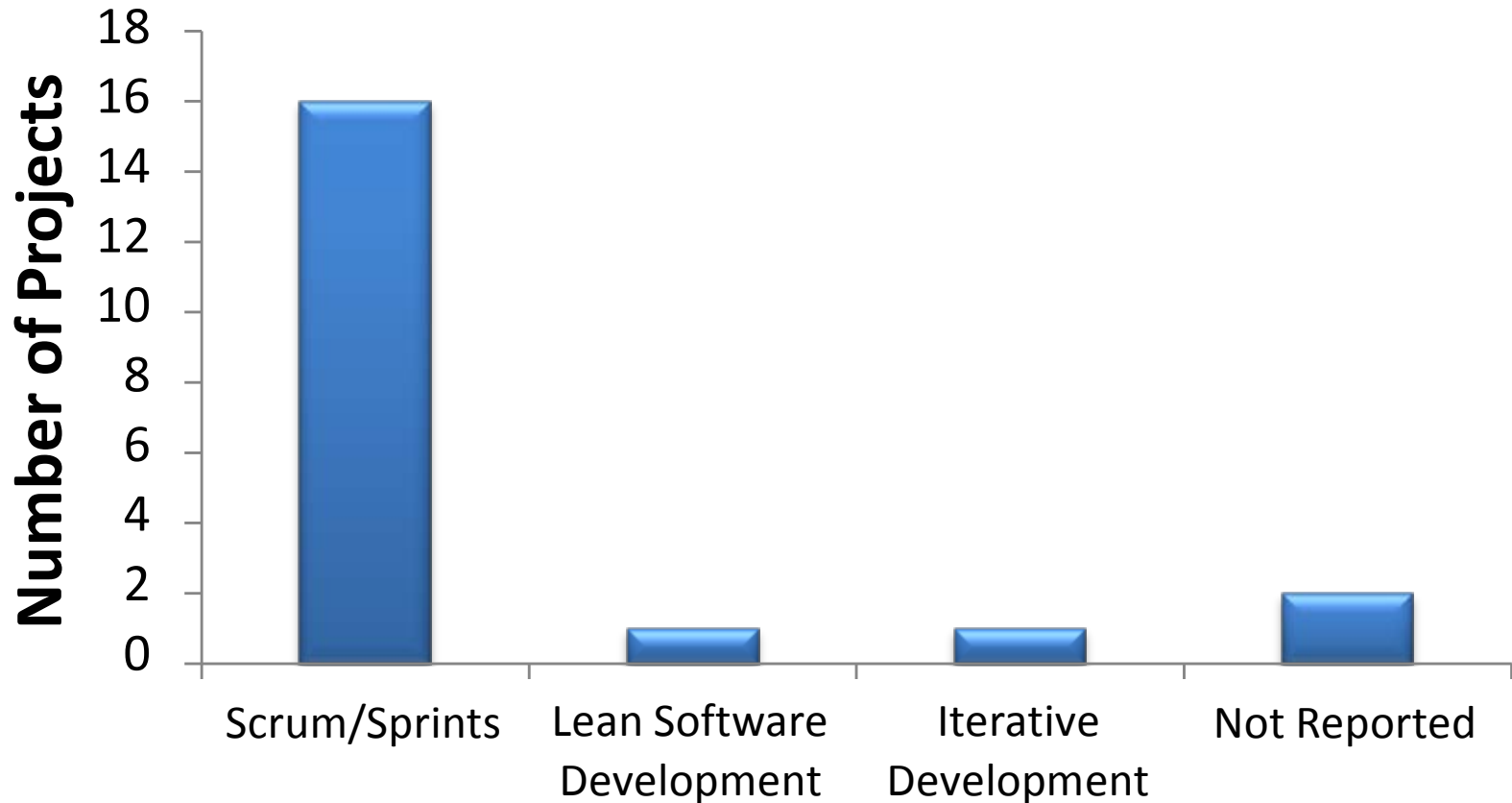


# Dataset by Delivery Year



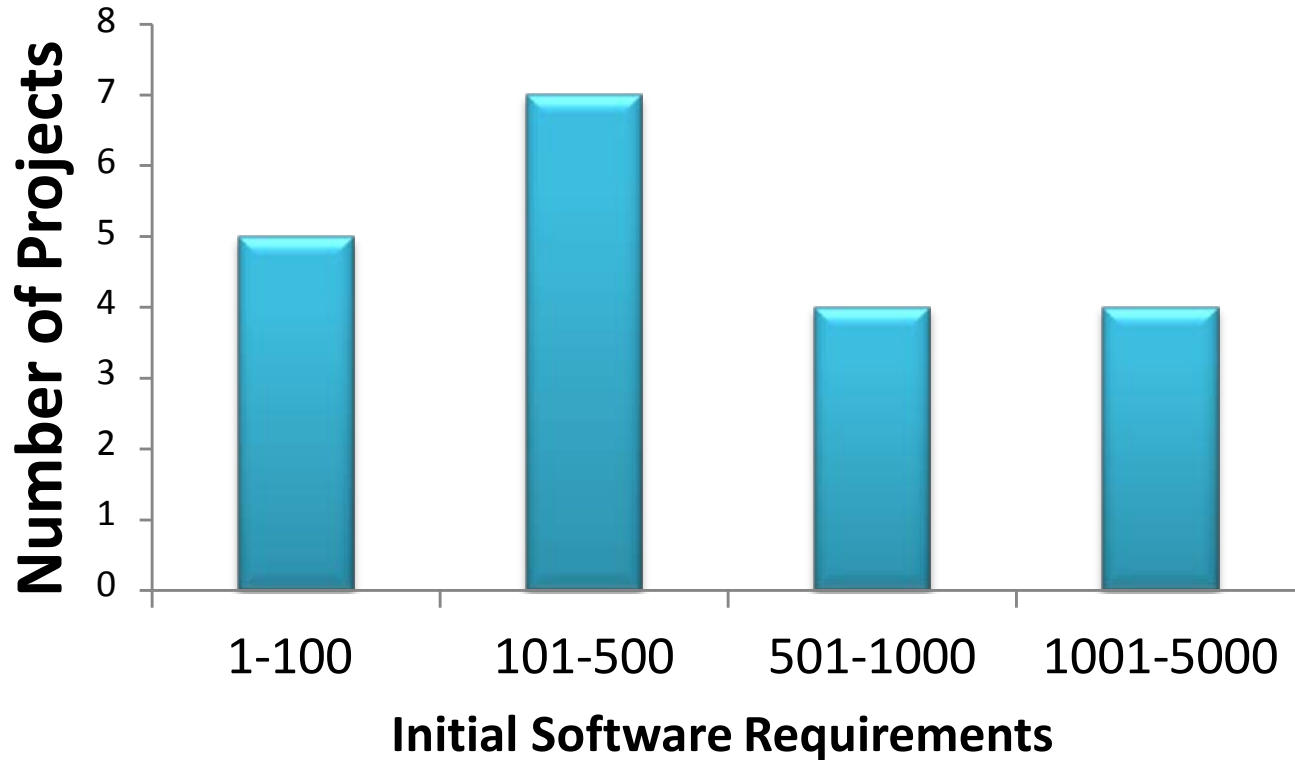
# of completed Agile Projects (reported in CADE) have increased since 2014

# Dataset by Agile Framework



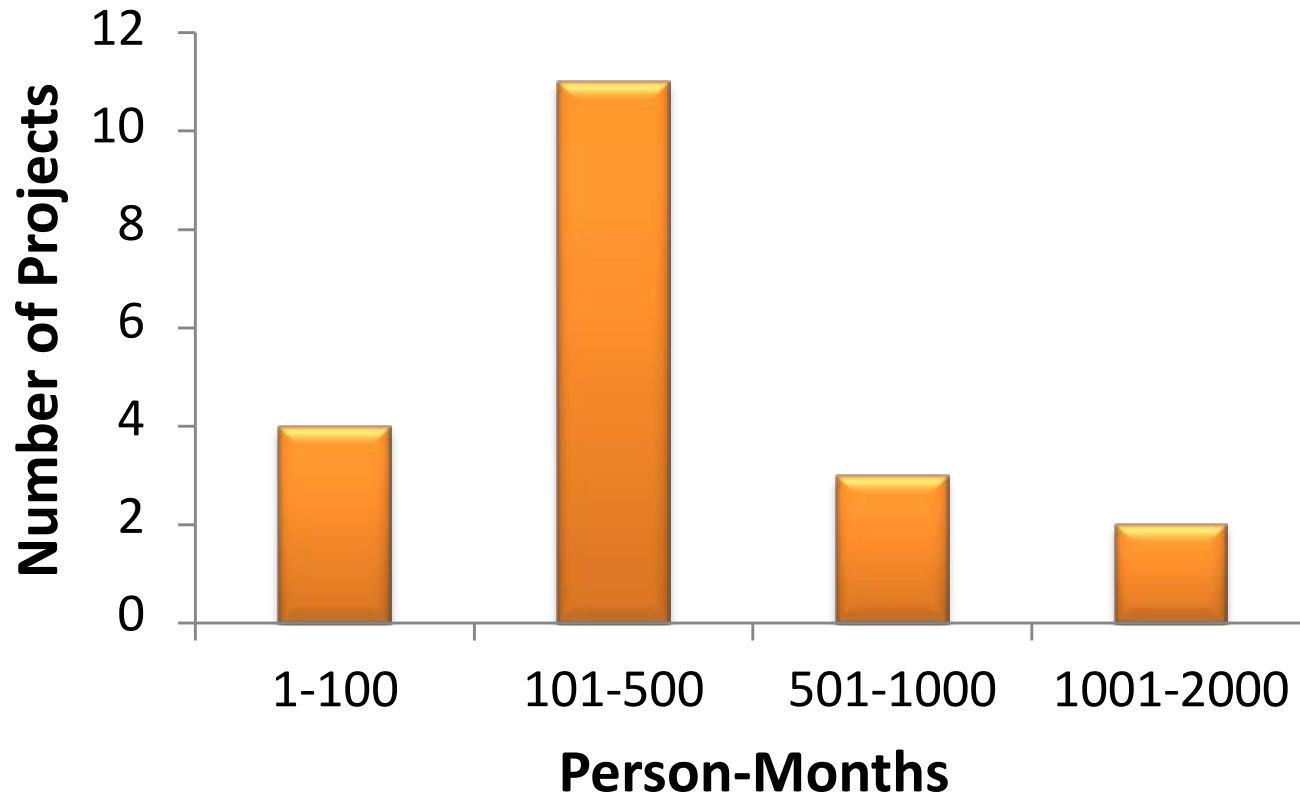
SRDR submissions provided limited information about Agile Framework  
Future SRDR submissions will require developers to describe their Agile process

# Dataset by Software Size\* Range



Average software size is 704 Software Requirements

# Dataset by Expended Effort (in Person-Months)



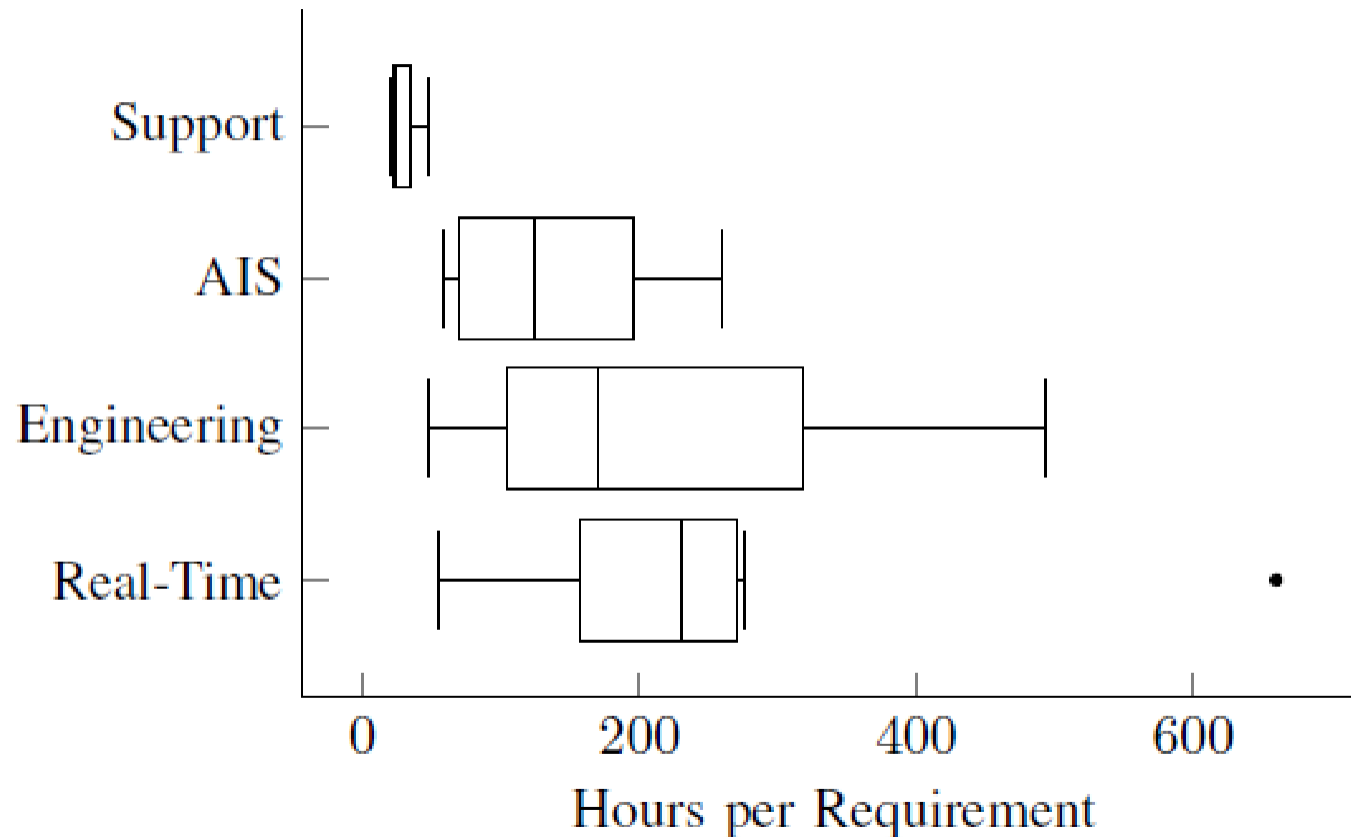
Average expended effort is 409 Person-Months

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# Productivity Benchmarks

# Productivity by Super Domain



Grouping by Software Domain shows significant effect on **Agile Software Productivity**

# Productivity Comparison Agile vs Non-Agile

Average Productivity\*

Size Range	Agile	Non-Agile
1-100	0.37	0.33
101-500	0.96	0.80
501-5000	1.97	1.16
Composite Average	0.8	0.66

\* Initial Software Requirements per Person-Months

When grouped by Size, Agile Software Projects appear to be more productive

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# Agile Effort Estimation Models



# Agile Effort Model Variables

Name	Acronym	Type	Definition
Final Effort	EFFORT	Dependent	Actual software engineering effort (in Person-Months) at contract completion
<b>Initial</b> Software Requirements	REQ	Independent	Sum of Initial Functional Requirements and Initial External Interface Requirements collected <b>at contract award</b> . Counting convention based on “shall statements”
<b>Initial</b> Peak Staff	STAFF	Independent	Estimated peak team size <b>at contract award</b> , measured in full-time equivalent staff
Super Domain	SD	Categorical	Software primary application. Four Types: Mission Support, Automated Information System (AIS), Engineering, or Real Time

# Agile Effort Estimation Model (Single Variable)

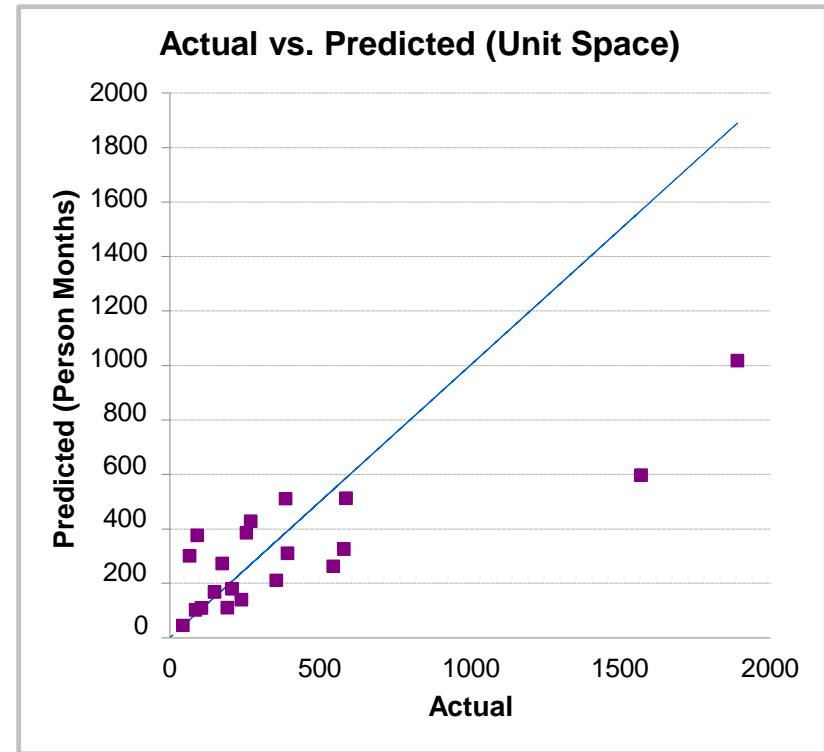
Model	Equation Form	N	R <sup>2</sup> %	CV%	Mean	MMRE%	REQ Min	REQ Max
1	Effort = 14.5 x REQ <sup>0.5009</sup>	20	53	48	409	64	10	4,867

Effort = Final Effort (in Person Months) at contract completion

REQ = Initial Software Requirements at contract start

## Coefficient Statistics:

Variable	P-value	VIF
Intercept	0.0000	
REQ	0.0002	
STAFF		
SD		



**Agile Estimation Model not accurate when simply using REQ as input**

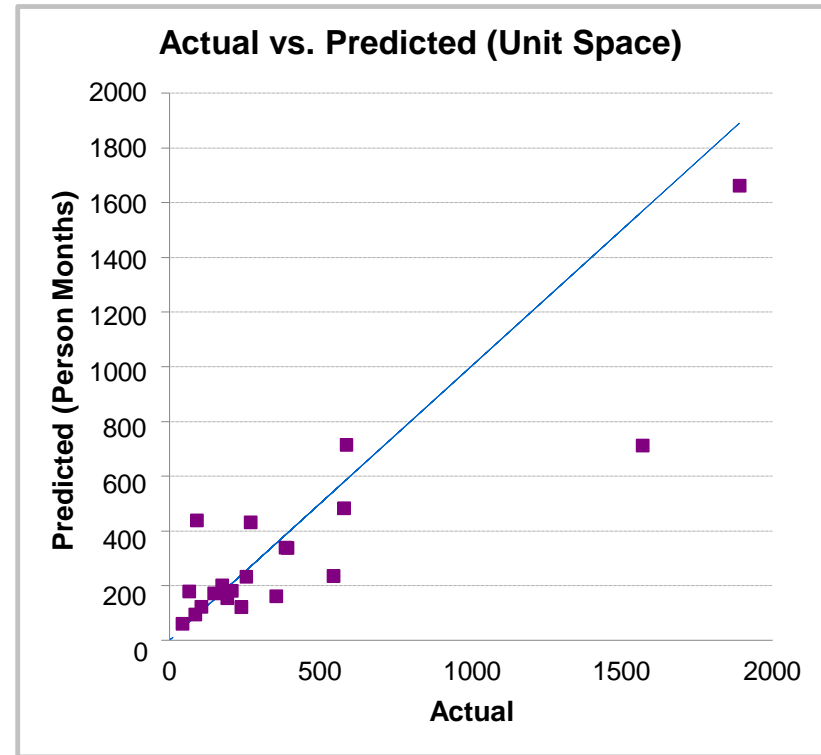
# Agile Effort Estimation Model (Two Variables)

Model	Equation Form	N	R <sup>2</sup> %	CV%	Mean	MMRE %	REQ Min	REQ Max
2	Effort = 6.8 x REQ <sup>0.4071</sup> x STAFF <sup>0.4404</sup>	20	60	36	409	52	10	4,867

- Effort = Final Effort (in Person Months) at contract completion
- REQ = Initial Software Requirements at contract start
- STAFF = Initial (or Estimated) Peak Staff at contract start

## Coefficient Statistics:

Variable	P-value	VIF
Intercept	0.0000	
REQ	0.0015	1.22
STAFF	0.0559	1.22
SD		



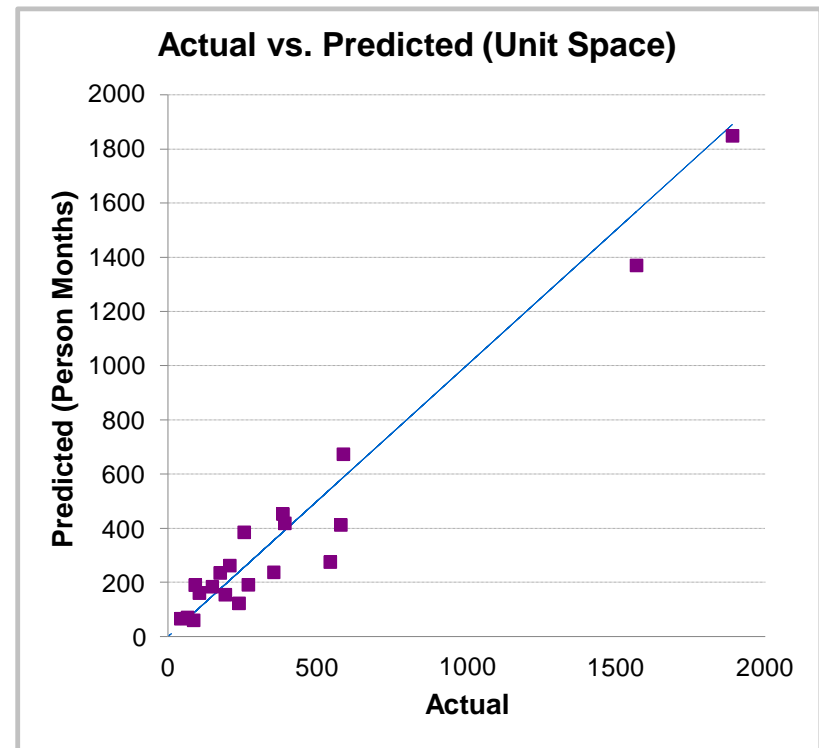
# Agile Effort Estimation Model (Three Variables)

Mod	Equation Form	N	R <sup>2</sup> %	CV %	Mean	MMRE %	REQ Min	REQ Max
3	Effort = 1.3 x REQ <sup>0.5126</sup> x STAFF <sup>0.4782</sup> x SD <sup>1.001</sup>	20	81	22	409	32	10	4,867

- Effort = Final Effort (in Person Months) at contract completion
- REQ = Initial Software Requirements at contract start
- STAFF = Initial (or Estimated) Peak Staff at contract start
- SD = 1 for Mission Support Super Domain (SD)  
2 for Automated Information System SD  
3 for Engineering SD  
4 for Real Time SD

## Coefficient Statistics:

Variable	P-value	VIF
Intercept	0.0000	
REQ	0.0000	1.45
STAFF	0.0045	1.37
SD	0.0003	1.07



Agile Estimation Model more accurate when all 3 variables are added

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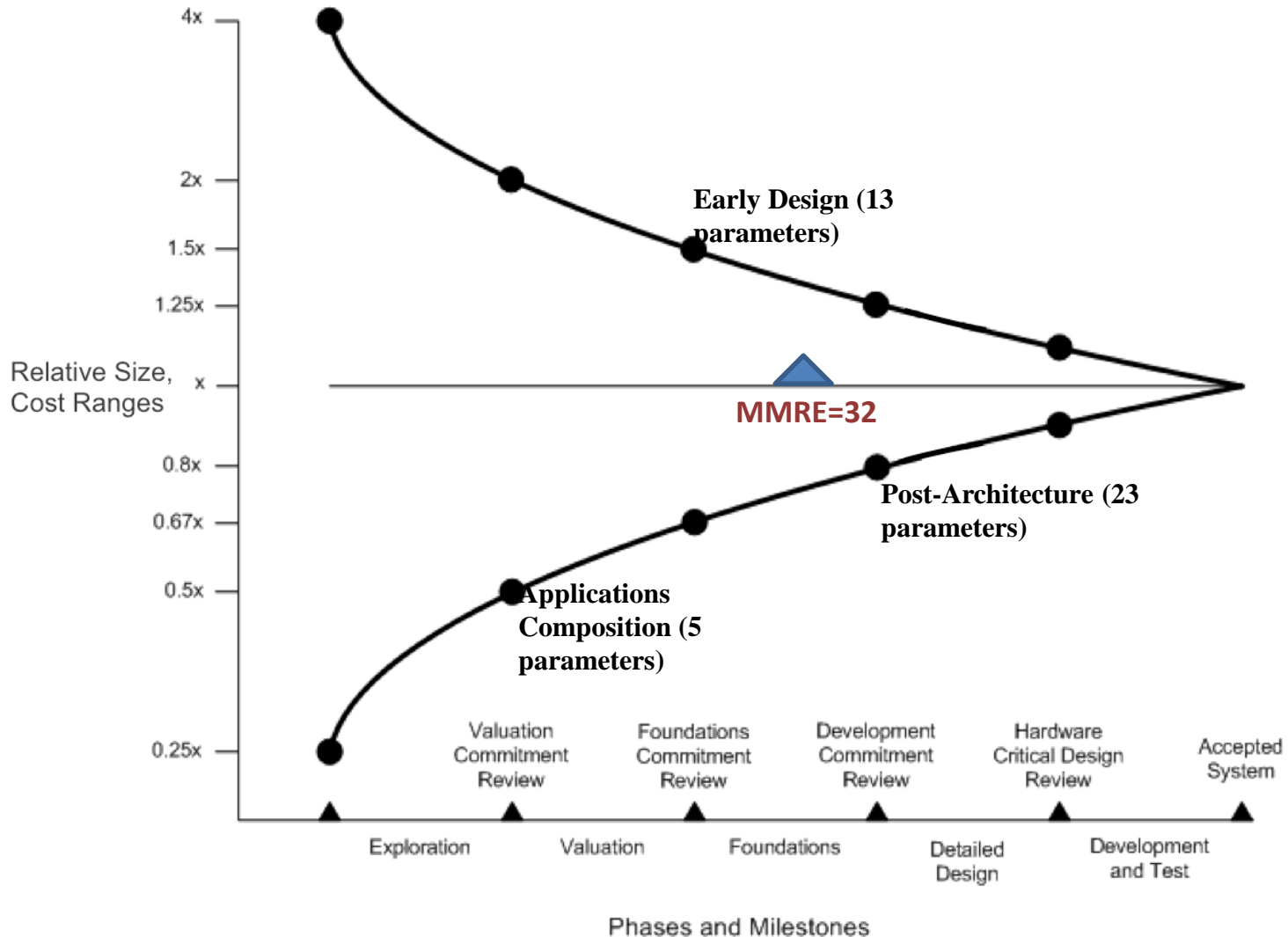
# Conclusion

# Primary Findings

- ü Initial Software Requirements\* is a valid size proxy for Software Effort Estimation Models
- ü Models' accuracy improves when Peak Staff and Super Domain, are treated along with Initial Software Requirements\*

Model	Equation Form	N	R <sup>2</sup> %	CV%	MMRE%
1	Effort = 14.5 x REQ <sup>0.5009</sup>	20	53	48	64
2	Effort = 6.8 x REQ <sup>0.4071</sup> x STAFF <sup>0.4404</sup>	20	60	36	52
3	Effort = 1.3 x REQ <sup>0.5126</sup> x STAFF <sup>0.4782</sup> x SD <sup>1.001</sup>	20	81	22	32

# The Cone of Uncertainty



# Model **L**imitations and **U**sefulness

- v **S**ince data was analyzed at the CSCI level, effort models may not be appropriate for projects reported at the Roll-Up Level.
- v **D**o not use Effort Estimation Models if your input parameters are outside of the model's dataset range.
- ü **P**roposed Effort Models may be used to either crosscheck or validate contract proposals as input parameters used in the study are typically available during proposal evaluation phase
- ü **A**pplicable for both, Defense and Business Systems
- ü **A**pplicable for Agile Software Projects