Process-Related Effort and Schedule Estimating Relationships for Software Cost Estimating



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Outline

- Introduction
- Experimental Design
- Data Analysis
- Descriptive Statistics
- Effort Models
- Schedule Models
- Conclusion



Frequently Used Terms

- **CMMI**: Capability Maturity Model Integrated (a ranking certified by the CMMI Institute of process maturity)
- **CPAF**: Cost Plus Award Fee (type of contract)
- **CPIF**: Cost Plus Incentive Fee (type of contract)
- **CPFF**: Cost Plus Fixed Fee (type of contract)
- **Primary Programming Language** (one language, usually out of many, which is considered primary as the majority of the software code is made up of this language)

Introduction



Problem Statement

- Software estimates must account for the evolution of requirements, knowledge, processes, and tools
 - Programming languages require specialized knowledge; capabilities often include debugging tools and code libraries
 - Capability Maturity Model Integrated (CMMI) certification for organizations demonstrating specific, routine processes at the levels 3 through 5
 - Cost-plus contract types recommended for exploratory studies, demonstrations, and development



- This study will highlight elements of project size from paired initial-final Computer Software Configuration Item (CSCI) records to estimate in new categories
- Perform statistical analysis on sizing parameters such as
 - Estimated functional requirements
 - Estimated source lines of code (SLOC) in logical statements (LS)
 - Estimated new SLOC in LS
 - Estimated effort
 - Estimated duration
- Highlight differences in effect of sizing parameters by using new estimation categories



Research Questions

- By using process-oriented categories, will data available at the initial project stage help predict effort hours?
- 2) Will any of this data help predict schedule duration?
- 3) Are estimated effort hours and schedule duration useful to predict actual effort hours and schedule duration?

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Experimental Design



Quantitative Method

- Non-random sample of secondary data
- Projects reported at the CSCI level for early program phases, beginning to elaborate system requirements
- To minimize threats to validity, the analysis framework focused on estimated inputs rather than final inputs



Instrumentation

- Questionnaire:
 - Software Resource Data Report (SRDR) (DD-Form 2630)
- Content:
 - Allows for the collection of project context, responsible company or government information, certified maturity level, requirements, product size, effort, and schedule
- Source:
 - Cost Assessment Data Enterprise (CADE) website: <u>http://cade.osd.mil/Files/Policy/Initial_Developer_Report.xlxs</u> <u>http://cade.osd.mil/Files/Policy/Final_Developer_Report.xlxs</u>



Sample and Population

Empirical data from 408 recent records
 – 204 paired initial and final records





Data Analysis Pedigree



Project Delivery Year





Primary Programming Language



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Aggregated Primary Language

Symbol	Definition
Ada	Ada is a structured, object-oriented, high-level language unique in providing support
	for real-time embedded software with tasks and synchronous messages
C#	C# (pronounced "C-sharp") is an object-oriented programming language from
	Microsoft based on C++ and designed to work with Microsoft's .Net platform to
	facilitate information exchange, Web services, and highly portable applications
C/C++	Hybrid of C and C++: C was created to run on the UNIX operating system and is not
	an object-oriented language. C and C++ were designed for systems programmers
C++	C++ compiles directly to a machine's native code, allowing it to run fast, if optimized.
	Allows type conversions to be checked at compile-time or run-time. C++ supports
	procedural, generic, and object-oriented programming paradigms. Code using C++'s
	standard library will run on many platforms with few to no changes. C++, as a
	language directly built off C, is compatible with almost all C code
Java	Java is a language for use in the Internet's distributed environment. Designed with
	the "look and feel" of C++, it is simpler to use, enforcing an object-oriented
	programming model. Java may create complete applications to run on a single
	computer or be distributed among servers and clients in a network. Java can also be
	used to build small application modules or applets as part of a Web page



CMMI Level





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CMMI Level

Capability Maturity Model Integration (CMMI) is a way to assess and describe an organization's software development process, compare it against industry standards and help the organization refine and improve that process.



QUICK STUDY: CMMI

Russell, Kay Computerworld; Jan 24, 2005; 39, 4; ProQuest Research Library pg. 28 Presented at the 2016 ICEAA Professional Development & Training Workshop - www.iceaaonline.com/atlanta2016



Contract Type



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Contract Type

Contract Types	Symbol	Definition
Cost Plus Award Fee	CPAF	The contract level of effort is uncertain and it is not feasible or effective to negotiate an adjustment formula. The likelihood of meeting objectives can be enhanced by a clear subjective fee plan.
Cost Plus Fixed Fee	CPFF	Cost uncertainty is so great that establishment of predetermined targets and incentive sharing arrangements could result in a final fee out of line with the actual work
Cost Plus Incentive Fee	CPIF	Cost uncertainties are so great that any fixed-price contract would force the contractor to accept an unreasonable risk, but reasonable targets and formulas for sharing costs may be negotiated



Model Reliability and Validity

Measure	Symbol	Description
Number of Records	n	The number of records used in the model
Coefficient of Variation	CV	Percentage expression of the standard error compared to the mean of the dependent variable. This is a relative measure allowing direct comparison among models.
P-value	α	Level of statistical significance established through the coefficient alpha ($p \le \alpha$)
Coefficient of Determination	R ²	The Coefficient of Determination shows how much variation in the dependent variable is explained by the regression equation.
t-test	t-stat	Provides a measure of the significance of the predictor variables in the regression model. The variable is significant when the t-stat is greater than the two-tailed value, given the degrees of freedom and coefficient alpha ($\alpha = 0.05$)
Mean Magnitude of Relative Error	MMRE	Mean Magnitude of Relative Error (MRE) measures differences between actual and predicted values relative to the actual value. The mean is computed using every observation.
Prediction Accuracy	PRED(30)	Prediction accuracy is rated as a percentage of the number of records below an individual MRE \leq 0.30

Data Analysis



Pairwise Correlation Analysis

- Variable selection based on Pairwise Correlation
 - Pairwise correlation chosen over structural equation modeling as the number of observations by subset was below the minimum observations (i.e. 200) needed
 - Variables examined

Actual Effort Actual Duration Estimated CSCI Requirements Estimated Peak Staff Estimated Total SLOC in LS Estimated New Code in LS Estimated Effort Estimated Duration



Primary Language Pairwise Correlation Analysis

- Actual Effort Hours
 - For all languages, Actual Effort Hours are correlated to Estimated Effort Hours
 - C# actual effort is correlated to Estimated New Code (LS) [<u>New</u>], Estimated SLOC (LS) [<u>SLOC</u>], and Estimated Peak Staff [<u>PS</u>]
 - Java actual effort is correlated to PS and SLOC
 - Ada, C/C++, and C++ actual effort is correlated to PS and New
- Actual Duration
 - For all languages, Actual Duration is correlated to Estimated Duration (in months)
 - C# duration is correlated to SLOC
 - C++ duration is correlated to Estimated Requirements [<u>*REQ*</u>]













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NUMBER OF ALL	1.25		144		4.04	-1.76	
Asteal Deattern		8.25	8.71	4.7		8.18	
Entroping Dist.			+34	4.34		-6/73	
Estimated Real Instants	I '			8.9	1.04	5.45	
Entropied Duration	1				4.04	0.10	
Estimates Peak Stuff	1					0.000	
Saturated New SLOC + US							
Entrated BLOC # 18							

CMMI Pairwise Correlation Analysis

- For all CMMI levels, Actual Effort Hours are correlated to Estimated Effort Hours
- CMMI 3 is correlated to PS, New, and SLOC
- CMMI 4 is correlated to New and SLOC
- CMMI 5 is correlated to PS and New

- For all CMMI levels, Actual Duration is correlated to Estimated Duration
- CMMI 4 is correlated to REQ and SLOC





CMMI-4 Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.31	0.95	0.21	0.18	0.04	0.59	0.74
Actual Duration	1	0.09	0.83	0.91	0.57	0.40	0.59
Estimated Effort		1	-0.06	0.00	-0.07	0.61	0.73
Estimated Requirements			1	0.79	0.23	0.12	0.23
Estimated Duration				1	0.39	0.19	0.53
Estimated Peak Staff					1	0.33	0.3
Estimated New SLOC in LS						1	0.5
Estimated SLOC in LS							

CMMI-4 Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.39	0.88	0.06	0.22	0.24	0.78	0.65
Actual Duration	1	0.06	0.47	0.96	0.57	0.45	0.66
Estimated Effort		1	0.85	-0.10	0.01	0.73	0.57
Estimated Requirements			1	0.80	0.42	0.39	0.67
Estimated Duration				1	0.45	0.31	0.62
Estimated Peak Staff					1	0.39	0.26
Estimated New SLOC in LS						1	0.76
Estimated SLOC in LS							1

CMMI-5 Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.12	0.85	0.33	-0.11	0.67	0.57	0.17
Actual Duration	1	-0.13	0.17	0.61	-0.16	-0.02	0.06
Estimated Effort		1	0.35	-0.12	0.67	0.58	0.21
Estimated Requirements	1		1	0.08	0.36	0.22	0.10
Estimated Duration	1			1	-0.10	0.00	0.07
Estimated Peak Staff	1				1	0.50	0.14
Estimated New SLOC in LS	1					1	0.27
Estimated SLOC in LS							1

CMMI-5 Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.03	0.86	-0.03	-0.02	0.71	0.72	0.48
Actual Duration	1	-0.03	0.56	0.75	-0.13	-0.01	0.03
Estimated Effort		1	0.13	-0.02	0.77	0.79	0.52
Estimated Requirements			1	0.13	0.50	0.47	0.41
Estimated Duration				1	-0.05	-0.02	0.08
Estimated Peak Staff					1	0.65	0.52
Estimated New SLOC in LS						1	0.58
Estimated SLOC in LS							1

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Contract Type Pairwise Correlation Analysis

- For all cost plus contracts, Actual Effort Hours are correlated to Estimated Effort Hours
- CPAF is correlated to PS, New, and SLOC
- CPFF is correlated to New
- CPIF is correlated to PS

- For all cost plus contracts, Actual Duration is correlated to Estimated Duration (in months)
- CPAF is correlated to REQ
- CPIF is correlated to New and SLOC



Descriptive Statistics

Criteria for Analysis

- Subsets are clearly separated and defined (e.g., no "unknowns" or "notspecified")
- Number of records in subset ≥ 12





Estimated Effort Hours Box Plots by Analysis Category



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Actual Effort Hours Box Plots by Analysis Category

300,000 250,000 -200,000 ÷ 150,000 -100,000 -۰. ×. . . . ż ÷ ۰, 50,000ł 5 ŝ, ¥. ę ŝ ł 1.1 0 C# C/C++C++ Java CPAF CPFF CPIF CMMI3 CMMI4 CMMI5 Ada Cost Plus **Process Maturity Level** Aggregated Primary Language Contract Type

Actual Effort Hours

Where 15 rows are excluded

Process Maturity Level



Percent Change in Effort Hours (magnified) Box Plots by Analysis Category



Cost Plus

Contract Type

Aggregated Primary Language



Estimated Duration Box Plots by Analysis Category



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Actual Duration Box Plots by Analysis Category



Actual Duration in Months

Where 15 rows are excluded

Percent Change in Duration (magnified) Box Plots by Analysis Category

Percent Change in Duration from Estimated to Actual





Actual Hours Per Estimated Requirements (magnified) Box Plots by Analysis Category



Effort and Schedule Models

Model Acceptance Criteria

Measure	Criterion
MAD	≤ 45%
CV	≤ 45%
R^2	≥ 55%
t-test	> Two tailed critical value (α = 0.05)

 Zero / blank input values were excluded to generate comparative CERs and SERs





Effort Models

Model	Subset	Records	Equation	R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/ Avg Act)	MMRE	PRED(30)	Minimum Value	Maximum Value
												eN	EW
1	C#	12	aEH = 18.97 * eNEW ^0.70	0.87	0.69	19556.6	0.39	0.29	0.29	0.29	0.67	3500	192000
												eE	H
2	Ada	25	aEH = 52.91 * eEH ^ 0.64	0.83	0.78	16824.6	0.55	0.40	0.29	0.40	0.48	320	133855
3	C#	12	aEH = 4.64 * eEH ^ 0.84	0.80	0.81	15390.6	0.64	0.38	0.25	0.38	0.58	4520	133280
4	C/C++	55	aEH = 6.82 * eEH ^ 0.85	0.80	0.66	32218.1	0.67	0.45	0.32	0.45	0.45	184	170807
5	C++	69	aEH = 1.55 * eEH ^ 0.98	0.89	0.85	26022.7	0.52	0.36	0.24	0.36	0.52	520	209616
												eE	H
6	CPAF	74	aEH = 8.53 * eEH ^ 0.82	0.79	0.64	28741.6	0.78	0.51	0.35	0.51	0.46	575	169583
7	CPFF	40	aEH = 1.27 * eEH ^ 0.99	0.71	0.78	15281.0	1.11	0.58	0.31	0.58	0.50	1896	101665
8	CPIF	43	aEH =18.8 * eEH ^0.75	0.66	0.70	35749.2	0.84	0.49	0.28	0.49	0.60	2235	191013
												eEH	
9	CMMI 3	77	aEH = 4.46 * eEH ^ 0.88	0.82	0.76	29210	0.75	0.49	0.29	0.49	0.42	575	209616
10	CMMI 4	16	aEH = 7.91 * eEH ^ 0.84	0.83	0.88	22811	0.27	0.22	0.17	0.22	0.75	11702	207968
11	CMMI 5	90	aEH = 9.08 * eEH ^ 0.80	0.71	0.69	28265	1.03	0.55	0.34	0.55	0.47	1104	225304



Effort Models' Validity

Model	Subset	Records	Independent Variable T-Statistic (Coef/SD)	P-Value
1	C#	12	4.8554	0.0007
2	Ada	25	9.0249	0.0000
3	C#	12	6.3417	0.0000
4	C/C++	55	14.5753	0.0000
5	C++	69	23.5838	0.0000
6	CPAF	74	16.2532	0.0000
7	CPFF	40	9.7535	0.0000
8	CPIF	43	8.9502	0.0000
9	CMMI 3	77	18.7147	0.0000
10	CMMI 4	16	8.2148	0.0000
11	CMMI 5	90	14.8412	0.0000



Schedule Models

Model	Subset	Records	Equation	R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res / Avg Act)	MMRE	PRED(30)	Minimum Value	Maximum Value	
												eSC	HED	
12	Ada	24	aSCHED = 2.14 * eSCHED ^0.76	0.65	0.63	16.9	4.73	1.39	0.35	1.39	0.46	0.2	100.1	
13	C#	12	aSCHED = 1.55 * eSCHED ^0.87	0.95	0.81	6.6	0.30	0.23	0.16	0.23	0.75	0.5	52.0	
14	C++	69	aSCHED = 1.44 * eSCHED ^0.92	0.86	0.69	11.9	0.63	0.37	0.26	0.37	0.57	0.2	83.0	
15	Java	24	aSCHED = 2.4 * eSCHED ^0.75	0.81	0.87	4.9	0.46	0.31	0.16	0.31	0.67	0.4	47.2	
												eSC	eSCHED	
16	CPFF	40	aSCHED = 1.04 * eSCHED ^ 1.07	0.95	0.78	8.0	0.34	0.23	0.21	0.23	0.68	0.4	41.0	
17	CPIF	43	aSCHED = 1.40 * eSCHED ^0.80	0.76	0.64	16.3	4.79	1.05	0.48	1.05	0.47	0.2	100.1	
												eSC	HED	
18	CMMI 3	77	aSCHED = 2.23 * eSCHED ^0.76	0.65	0.63	14.1	5.31	1.31	0.32	1.31	0.48	0.3	100.1	
19	CMMI 4	16	aSCHED = 1.05 * eSCHED ^ 1.02	0.98	0.78	7.1	0.23	0.15	0.23	0.15	0.94	1.3	46.8	
20	CMMI 5	90	aSCHED = 1.44 * eSCHED ^0.86	0.78	0.55	12.6	3.32	0.85	0.34	0.85	0.50	0.2	57.0	
												eREQ		
21	CMMI 4	16	aSCHED = 0.01 * eREQ ^0.99	0.72	0.63	9.2	1.07	0.66	0.42	0.66	0.38	97	3685	



Schedule Models' Validity

Model	Subset	Records	Independent Variable T-Statistic (Coef/SD)	P-Value
12	Ada	24	6.3190	0.0000
13	C#	12	14.3584	0.0000
14	C++	69	20.0534	0.0000
15	Java	24	9.7523	0.0000
16	CPFF	40	26.9108	0.0000
17	CPIF	43	11.5055	0.0000
18	CMMI 3	77	11.8238	0.0000
19	CMMI 4	16	23.6736	0.0000
20	CMMI 5	90	17.6696	0.0000
21	CMMI 4	16	5.9674	0.0000





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Analysis by C# Primary Language

C# Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.38	0.92	-0.02	0.46	0.79	0.84	0.74
Actual Duration	1	0.45	0.35	0.91	0.34	0.54	0.54
Estimated Effort		1	-0.07	0.59	0.78	0.86	0.82
Estimated Requirements			1	0.09	-0.14	-0.06	0.04
Estimated Duration				1	0.45	0.58	0.63
Estimated Peak Staff					1	0.76	0.75
Estimated New SLOC in LS						1	0.89
Estimated SLOC in LS							1

C# Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.49	0.84	0.54	0.50	0.69	0.90	0.78
Actual Duration	1	0.54	0.67	0.78	0.40	0.62	0.73
Estimated Effort		1	0.55	0.57	0.83	0.85	0.83
Estimated Requirements			1	0.27	0.44	0.59	0.69
Estimated Duration				1	0.41	0.63	0.69
Estimated Peak Staff					1	0.75	0.72
Estimated New SLOC in LS						1	0.87
Estimated SLOC in LS							1



Analysis by Java Primary Language

Java Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.00	0.79	0.61	-0.09	0.56	0.34	0.19
Actual Duration	1	0.01	-0.19	0.94	-0.16	-0.15	0.05
Estimated Effort		1	0.67	-0.06	0.71	0.37	0.16
Estimated Requirements			1	-0.33	0.81	0.50	0.37
Estimated Duration				1	-0.24	-0.19	-0.01
Estimated Peak Staff					1	0.55	0.37
Estimated New SLOC in LS						1	0.45
Estimated SLOC in LS							1

Java Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.20	0.77	-0.18	-0.18	0.68	0.60	0.62
Actual Duration	1	-0.18	0.60	0.90	-0.38	-0.12	-0.03
Estimated Effort		1	-0.19	-0.16	0.82	0.68	0.57
Estimated Requirements			1	-0.28	0.69	0.67	0.57
Estimated Duration				1	-0.34	-0.14	-0.03
Estimated Peak Staff					1	0.58	0.60
Estimated New SLOC in LS						1	0.65
Estimated SLOC in LS							1



Analysis by Ada Primary Language

Ada Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.26	0.92	0.35	0.27	0.50	0.71	0.27
Actual Duration	1	-0.04	0.11	0.87	-0.37	0.41	0.16
Estimated Effort		1	0.26	0.00	0.56	0.51	0.16
Estimated Requirements			1	-0.05	0.38	0.23	0.27
Estimated Duration				1	-0.26	0.36	-0.10
Estimated Peak Staff					1	0.26	-0.01
Estimated New SLOC in LS						1	0.41
Estimated SLOC in LS							1

Ada Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.12	0.92	0.02	0.22	0.78	0.81	0.43
Actual Duration	1	0.02	0.49	0.81	-0.24	0.21	0.11
Estimated Effort		1	0.19	0.12	0.73	0.79	0.37
Estimated Requirements			1	0.03	0.44	0.61	0.41
Estimated Duration				1	-0.07	0.28	-0.16
Estimated Peak Staff					1	0.64	0.37
Estimated New SLOC in LS						1	0.50
Estimated SLOC in LS							1



Analysis by C/C++ Primary Language

C / C++ Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.07	0.82	0.48	-0.05	0.71	0.57	0.36
Actual Duration	1	-0.10	0.31	0.69	0.10	0.12	0.03
Estimated Effort		1	0.26	-0.15	0.61	0.62	0.52
Estimated Requirements			1	0.22	0.41	0.32	0.24
Estimated Duration				1	0.14	0.04	-0.05
Estimated Peak Staff					1	0.53	0.46
Estimated New SLOC in LS						1	0.42
Estimated SLOC in LS							1

C / C++ Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.12	0.89	-0.05	-0.12	0.75	0.76	0.49
Actual Duration	1	-0.05	0.45	0.78	0.06	0.02	0.11
Estimated Effort		1	0.17	-0.10	0.75	0.83	0.50
Estimated Requirements			1	0.11	0.42	0.34	0.47
Estimated Duration				1	0.12	0.04	0.04
Estimated Peak Staff					1	0.66	0.58
Estimated New SLOC in LS						1	0.49
Estimated SLOC in LS							1



Analysis by C++ Primary Language

C++ Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.12	0.93	0.35	0.11	0.62	0.57	0.39
Actual Duration	1	0.15	-0.11	0.69	-0.05	0.02	0.22
Estimated Effort		1	0.23	0.23	0.56	0.54	0.37
Estimated Requirements			1	-0.10	0.23	0.02	0.06
Estimated Duration				1	-0.07	0.03	0.22
Estimated Peak Staff					1	0.45	0.21
Estimated New SLOC in LS						1	0.24
Estimated SLOC in LS							1

C++ Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.20	0.95	0.23	0.15	0.74	0.78	0.65
Actual Duration	1	0.23	0.71	0.79	0.03	0.10	0.27
Estimated Effort		1	0.25	0.24	0.77	0.77	0.63
Estimated Requirements			1	0.26	0.64	0.48	0.53
Estimated Duration				1	0.04	0.10	0.34
Estimated Peak Staff					1	0.65	0.54
Estimated New SLOC in LS						1	0.53
Estimated SLOC in LS							1



Analysis by CMMI 3

CMMI-3 Pearson Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.28	0.88	0.42	0.23	0.74	0.50	0.48
Actual Duration	1	0.35	-0.09	0.83	0.03	0.27	0.24
Estimated Effort		1	0.28	0.37	0.74	0.49	0.49
Estimated Requirements			1	-0.11	0.33	0.07	0.08
Estimated Duration				1	-0.01	0.22	0.13
Estimated Peak Staff					1	0.55	0.45
Estimated New SLOC in LS						1	0.31
Estimated SLOC in LS							1

CMMI-3 Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.29	0.92	0.38	0.28	0.77	0.73	0.71
Actual Duration	1	0.38	0.61	0.86	0.14	0.32	0.31
Estimated Effort		1	0.18	0.40	0.83	0.78	0.70
Estimated Requirements			1	0.13	0.57	0.49	0.58
Estimated Duration				1	0.15	0.33	0.18
Estimated Peak Staff					1	0.65	0.68
Estimated New SLOC in LS						1	0.61
Estimated SLOC in LS							1



Analysis by CMMI 4

CMMI-4 Pearson Correlation	ActualEstimatedEstimatedEstimatedEstimatedDurationEffortRequirementsDurationF		Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS		
Actual Effort	0.31	0.95	0.21	0.18	0.04	0.59	0.74
Actual Duration	1	0.09	0.83	0.91	0.57	0.40	0.59
Estimated Effort		1	-0.06	0.00	-0.07	0.61	0.72
Estimated Requirements			1	0.79	0.23	0.12	0.23
Estimated Duration				1	0.39	0.19	0.52
Estimated Peak Staff					1	0.33	0.31
Estimated New SLOC in LS		1	0.58				
Estimated SLOC in LS							1

CMMI-4 Spearman Correlation	Actual Duration	Actual Estimated Estimated Estimated Duration Effort Requirements Du		Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.39	0.88	0.06	0.22	0.24	0.78	0.65
Actual Duration	1	0.06	0.47	0.96	0.57	0.45	0.66
Estimated Effort		1	0.85	-0.10	0.01	0.73	0.57
Estimated Requirements			1	0.80	0.42	0.39	0.67
Estimated Duration				1	0.45	0.31	0.62
Estimated Peak Staff					1	0.39	0.26
Estimated New SLOC in LS						1	0.76
Estimated SLOC in LS							1



Analysis by CMMI 5

CMMI-5 Pearson Correlation	Actual Estimated Duration Effort		Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	-0.12	0.85	0.33	-0.11	0.67	0.57	0.17
Actual Duration	1	-0.13	0.17	0.61	-0.16	-0.02	0.06
Estimated Effort		1	0.35	-0.12	0.67	0.58	0.21
Estimated Requirements			1	0.08	0.36	0.22	0.10
Estimated Duration				1	-0.10	0.00	0.07
Estimated Peak Staff					1	0.50	0.14
Estimated New SLOC in LS		1	0.27				
Estimated SLOC in LS							1

CMMI-5 Spearman Correlation	arman Correlation Actual Estimated Estimated Estimated Duration Effort Requirements Duration		Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS	
Actual Effort	-0.03	0.86	-0.03	-0.02	0.71	0.72	0.48
Actual Duration	1	-0.03	0.56	0.75	-0.13	-0.01	0.03
Estimated Effort		1	0.13	-0.02	0.77	0.79	0.52
Estimated Requirements			1	0.13	0.50	0.47	0.41
Estimated Duration				1	-0.05	-0.02	0.08
Estimated Peak Staff					1	0.65	0.52
Estimated New SLOC in LS						1	0.58
Estimated SLOC in LS							1



Analysis by CPAF Contract Type

CPAF Pearson Correlation	Actual Estimated Duration Effort		Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.10	0.81	0.55	0.22	0.77	0.56	0.47
Actual Duration	1	0.10	-0.16	0.58	-0.09	0.23	0.17
Estimated Effort		1	0.35	0.23	0.71	0.68	0.56
Estimated Requirements			1	-0.14	0.41	0.12	0.06
Estimated Duration				1	0.12	0.24	0.13
Estimated Peak Staff					1	0.52	0.38
Estimated New SLOC in LS						1	0.33
Estimated SLOC in LS							1

CPAF Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.16	0.90	0.16	0.24	0.79	0.78	0.72
Actual Duration	1	0.16	0.67	0.71	-0.04	0.22	0.11
Estimated Effort		1	0.10	0.24	0.80	0.85	0.68
Estimated Requirements			1	0.08	0.59	0.51	0.54
Estimated Duration				1	0.15	0.30	0.06
Estimated Peak Staff					1	0.69	0.57
Estimated New SLOC in LS						1	0.68
Estimated SLOC in LS							1

CPFF Pearson Correlation	Actual Estimated Duration Effort		Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.16	0.90	0.60	0.21	0.59	0.76	0.28
Actual Duration	1	0.17	0.13	0.90	-0.06	0.14	0.33
Estimated Effort		1	0.55	0.23	0.54	0.67	0.27
Estimated Requirements			1	0.08	0.62	0.19	0.07
Estimated Duration				1	-0.02	0.20	0.27
Estimated Peak Staff					1	0.34	0.06
Estimated New SLOC in LS		1	0.35				
Estimated SLOC in LS							1

CPFF Spearman Correlation	Actual Duration	Actual DurationEstimated EffortEstimated RequirementsEstimated 		Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS	
Actual Effort	0.22	0.86	0.33	0.28	0.62	0.73	0.70
Actual Duration	1	0.33	0.69	0.88	-0.03	0.08	0.26
Estimated Effort		1	0.21	0.39	0.62	0.75	0.69
Estimated Requirements			1	0.32	0.54	0.54	0.55
Estimated Duration				1	-0.01	0.06	0.21
Estimated Peak Staff					1	0.61	0.55
Estimated New SLOC in LS						1	0.63
Estimated SLOC in LS							1

CPIF Pearson Correlation	Actual Estimated Duration Effort		Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.08	0.88	0.58	-0.06	0.57	0.45	0.51
Actual Duration	1	0.03	0.29	0.88	-0.01	0.12	0.20
Estimated Effort		1	0.41	-0.06	0.54	0.45	0.35
Estimated Requirements			1	0.08	0.56	0.59	0.60
Estimated Duration				1	-0.15	0.02	0.02
Estimated Peak Staff					1	0.60	0.64
Estimated New SLOC in LS						1	0.38
Estimated SLOC in LS							1

CPIF Spearman Correlation	Actual Duration	Estimated Effort	Estimated Requirements	Estimated Duration	Estimated Peak Staff	Estimated New SLOC in LS	Estimated SLOC in LS
Actual Effort	0.14	0.88	0.25	0.04	0.66	0.61	0.55
Actual Duration	1	0.25	0.65	0.85	0.08	0.24	0.22
Estimated Effort			0.20	0.13	0.75	0.60	0.59
Estimated Requirements			1	0.03	0.43	0.55	0.46
Estimated Duration				1	-0.14	0.10	-0.02
Estimated Peak Staff					1	0.59	0.80
Estimated New SLOC in LS						1	0.60
Estimated SLOC in LS]						1



Product Size Box Plots by Analysis Category



Estimated Requirements

6/20/2016



Product Size Box Plots by Analysis Category







Product Size Box Plots by Analysis Category



Estimated TOTAL SLOC in Logical Statements





Percent Change in Effort Hours Box Plots by Analysis Category



6/20/2016



Percent Change in Duration Box Plots by Analysis Category

Percent Change in Duration from Estimated to Actual



6/20/2016



Effort Hour Models Primary Language

Subset	Independent Variable(s)	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/Avg Act)	MMRE	PRED(25)	PRED(30)	Minimum Value	Maximum Value
														eN	EW
C#	Estimated New Code in LS	12	aEH = 18.97 * eNEW ^ 0.70	0.87	0.86	0.69	19556.57	0.39	0.29	0.29	0.29	0.58	0.67	3500	192000
														eE	H
Ada		25	aEH = 52.91 * eEH ^ 0.64	0.83	0.82	0.78	16824.57	0.55	0.40	0.29	0.40	0.48	0.48	320	133855
C#	Estimated	12	aEH = 4.64 * eEH ^ 0.84	0.80	0.78	0.81	15390.61	0.64	0.38	0.25	0.38	0.58	0.58	4520	133280
C/C++	Hours	55	aEH = 6.82 * eEH ^ 0.85	0.80	0.80	0.66	32218.08	0.67	0.45	0.32	0.45	0.44	0.45	184	170807
C++		69	aEH = 1.55 * eEH ^ 0.98	0.89	0.89	0.85	26022.71	0.52	0.36	0.24	0.36	0.39	0.52	520	209616



Subset	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/Avg Act)	MMRE	PRED(25)	PRED(30)	eEH Minimum	eEH Maximum
CPAF	74	aEH = 8.53 * eEH ^ 0.82	0.79	0.78	0.64	28741.58	0.78	0.51	0.35	0.51	0.38	0.46	575	169583
CPFF	40	aEH = 1.27 * eEH ^ 0.99	0.71	0.71	0.78	15280.97	1.11	0.58	0.31	0.58	0.45	0.50	1896	101665
CPIF	43	aEH = 18.8 * eEH ^ 0.75	0.66	0.65	0.70	35749.18	0.84	0.49	0.28	0.49	0.51	0.60	2235	191013



Subset	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/Avg Act)	MMRE	PRED(25)	PRED(30)	eEH Minimum	eEH Maximum
CMMI 3	77	aEH = 4.458 * eEH ^ 0.8825	0.82	0.82	0.76	29209.8	0.75	0.49	0.29	0.49	0.35	0.42	575	209616
CMMI 4	16	aEH = 7.912 * eEH ^ 0.8397	0.83	0.82	0.88	22810.9	0.27	0.22	0.17	0.22	0.69	0.75	11702	207968
CMMI 5	90	aEH = 9.08 * eEH ^ 0.8006	0.71	0.71	0.69	28264.7	1.03	0.55	0.34	0.55	0.41	0.47	1104	225304

Subset	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/Avg Act)	MMRE	PRED(25)	PRED(30)	eSCHED Minimum	eSCHED Maximum
Ada	24	aSCHED = 2.14 * eSCHED ^ 0.764	0.65	0.63	0.63	16.88	4.73	1.39	0.35	1.39	0.38	0.46	0.23	100.1
C#	12	aSCHED = 1.55 * eSCHED ^ 0.87	0.95	0.95	0.81	6.64	0.30	0.23	0.16	0.23	0.58	0.75	0.49	52.01
C++	69	aSCHED = 1.44 * eSCHED ^ 0.92	0.86	0.86	0.69	11.92	0.63	0.37	0.26	0.37	0.49	0.57	0.20	83.01
Java	24	aSCHED = 2.4 * eSCHED ^ 0.75	0.81	0.80	0.87	4.87	0.46	0.31	0.16	0.31	0.63	0.67	0.43	47.2



Subset	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/ Avg Act)	MMRE	PRED(25)	PRED(30)	Minimum	Maximum
													eS	CHED
CPFF	40	aSCHED = 1.039 * eSCHED ^ 1.069	0.95	0.95	0.78	7.96	0.34	0.23	0.21	0.23	0.68	0.68	0.36	41.00
CPIF	43	aSCHED = 1.397 * eSCHED ^ 0.8026	0.76	0.76	0.64	16.25	4.79	1.05	0.48	1.05	0.42	0.47	0.23	100.11



Subset	Records	Equation	R2 in Fit Space	Adjusted R2 in Fit Space	R2 in Unit Space	SE	RMS of % Errors	MAD	CV (MAD Res/ Avg Act)	MMRE	PRED (25)	PRED (30)	Minimum	Maximum
													eSC	HED
CMMI 3	77	aSCHED = 2.23 * eSCHED ^ 0.76	0.65	0.65	0.63	14.12	5.31	1.31	0.32	1.31	0.45	0.48	0.33	100.11
CMMI 4	16	aSCHED = 1.05 * eSCHED ^ 1.02	0.98	0.97	0.78	7.06	0.23	0.15	0.23	0.15	0.94	0.94	1.28	46.75
CMMI 5	90	aSCHED = 1.44 * eSCHED ^ 0.86	0.78	0.78	0.55	12.56	3.32	0.85	0.34	0.85	0.41	0.50	0.20	57.01
													eR	EQ
CMMI 4	16	aSCHED = 0.01 * eREQ ^ 0.99	0.72	0.70	0.63	9.21	1.07	0.66	0.42	0.66	0.31	0.38	97	3685