Software Cost Estimating Relationships

J. Leotta

Outline

- Introduction
- Background
- Data Description
- Regression Results
- Equation Details
- Problems
- Conclusions

Introduction

- Software is an important part of DOD programs
  - As systems are upgraded, much of the additional capability is achieved through software
  - As time goes on, software is a greater percentage of a program's cost than hardware

- **CONCERNS:**
  - *1/3 of all programs are delivered late and exceed their budget*
  - *2/3 of programs substantially exceed their budgets*

Background

- Simple formula:

$$E_d = C_k S_e$$

- More Complex Formula used in predictive models:

$$E_d = C_k \sum_{i=1}^{n} f_i S_e^{\beta}$$

- Where
  - E_d = the development effort in man hours
  - C_k = the productivity factor (defined as man-hours/ESLOC) and
  - S_e = the number of ESLOC
  - f_i = the i^{th} environmental factor
  - n = the number of environmental factors
  - β = an entropy factor that accounts for the productivity change as a function of effective product size

Source: Software Estimating Models: Three Viewpoints, by R.W. Jensen, L.H. Putnam, and W. Roetzheim

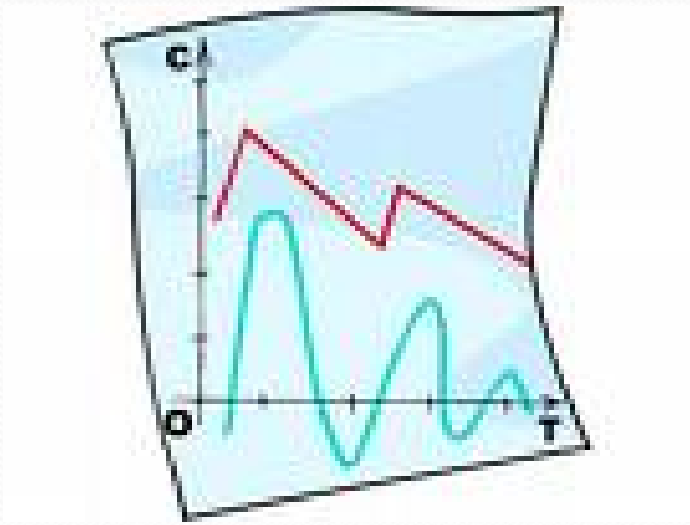
Data Description

- Software Requirements Data Reporting (SRDR) form (data ending in October 2008)
  - Examined completed programs
    - Over 600 data points overall
    - Some of the data points were incomplete

- Data was divided into sets:
  - All Data Points
  - Development Paradigm
  - Primary Development Language
  - Type of Program
  - Service
  - Contractor

Variables

- Variables used in the equations:
  - Independent:
    - ESLOC
    - Hrs/ESLOC
    - SW Requirements
    - Peak Staff
  - Dependent:
    - Duration
    - Hrs/ESLOC
  - Dummy:
    - CMMI



Regression Results

Dataset	Duration: ESLOC		Productivity: Peak Staff	
	Predicted	Actual	Predicted	Actual
Overall	+	+	-	-
Incremental	+	+	-	-
Sprial	+	+	-	-
Waterfall	+	+	-	-
Ada	+	+	-	-
C	+	+	-	-
Java	+	+	-	-
Avionics	+	+	-	-
C4I	+	+	-	-
Planning	+	+	-	-
Simulation	+	+	-	-
Training	+	+	-	+
Air Force	+	+	-	-
Army	+	+	-	-
Navy	+	+	-	-
BAE	+	+	-	-
Boeing	+	+	-	+
General Dynamics	+	+	-	-
Lockheed Martin	+	+	-	-
Northup Grumman	+	+	-	+
Raytheon	+	+	-	-

- First: Examination of predicted vs. actual results for two key relationships
  - Duration : ESLOC (positive)
  - Productivity : Peak Staff (negative)
  - *Yellow highlighted items reflect changes from predicted results*

Source for predicted results: "Next Generation Software Estimating Framework: 25 Years Later and Thousands of Projects Later" by M.A. Ross

Equation Details

- Tested the following 18 equations for all data sets:
  1. Duration = ESLOC, Peak Staff, Productivity
  2. Duration = ESLOC
  3. Duration = Peak Staff
  4. Duration = Productivity
  5. Duration = ESLOC, CMMI
  6. Duration = Productivity, CMMI
  7. Duration = ESLOC, Peak Staff
  8. Duration = ESLOC, CMMI, Peak Staff
  9. Duration = ESLOC, SW Requirements, Peak Staff
  10. Duration = SW Requirements, Peak Staff, ESLOC, CMMI
  11. Productivity = Peak Staff
  12. Productivity = ESLOC
  13. Productivity = Peak Staff, ESLOC
  14. Productivity = Peak Staff, SW Requirements
  15. Productivity = ESLOC, CMMI
  16. Productivity = SW Requirements, CMMI
  17. Productivity = Peak Staff, CMMI, SW Requirements
  18. Productivity = Peak Staff, CMMI, ESLOC

Best results from equations 2, 7, 9, and 12
(assessment based on statistical significance)

Equation Details (Cont)

- Example:
  - Equation 9
  - Java Data-set

- Duration = -47943 + 1.551 * ESLOC + 4.917 * Software Requirements - 650.6 * Peak staff
  - Statistics
    - R^2 = 94.92%
    - Standard Error = 83,244.62
    - Observations = 77

Correlation Matrix

	ESLOC	Productivity	Software Requirements	Peak Staff	CMMI	Duration
ESLOC	1.0000	-0.0101	0.7433	0.8322	0.2299	0.9684
Productivity	-0.0101	1.0000	0.0491	-0.0496	-0.0103	0.0609
Software Requirements	0.7433	0.0491	1.0000	0.5858	-0.5449	0.7830
Peak Staff	0.8322	-0.0496	0.5858	1.0000	0.0425	0.7844
CMMI	0.2299	-0.0103	-0.5449	0.0425	1.0000	0.1537
Duration	0.9684	0.0609	0.7830	0.7844	0.1537	1.0000

Problems with Results

- Requirements growth not accounted for in these simple equations

- The following table is a table of growth factors by segment and CMMI:

		Segment		
		Air	Ship	Shore
CMMI	3	1.70	1.60	1.50
	4	1.40	1.30	1.20
	5	1.20	1.18	1.10

Conclusion

- Variables that seem to have the best predictive results:
  - Size
  - Peak Staff
  - Software Requirements
- Data Set
  - Sorted by more than 1 factor to determine a good CER
- Implement a growth factor to account for changing requirements/risk

Back-Up Slides

-Data Sets

-Definitions of Variables

-Regression Results

1. Duration = ESLOC
2. Productivity = Peak Staff

-Summary of Statistical Significance

-Bibliography

Data Sets

- All data points
- Paradigm
  - Incremental
  - Spiral
  - Waterfall
- Primary Development Language
  - C (C, C++, and C #)
  - Java
  - Ada
- Type of Program
  - Avionics
  - C4I
  - Mission Planning
  - Training
- Service
  - Army
  - Air Force
  - Navy
- Contractor
  - BAE
  - Boeing
  - General Dynamics
  - Lockheed Martin
  - Northup Grumman
  - Raytheon

BACK

Definition of Variables

- **Dependent Variables:**
  - **Duration (Hours)**: A measure of total development effort; the number of staff-hours that were worked for each observation. Duration is thought of as an interval [T_{start}, T_{finish}]; or [o,t_p] where zero is the start and t_p represents the "p" number of increments necessary for completion (hours are used in our analysis). Total Effort is directly related to program duration, in other words, the sum of all people laboring to complete the task over time "t". The total time to develop SW includes actual development time, understanding, incorporating, changing, and verifying any legacy software.
  - **Productivity (Hours/ESLOC)**: This is a measure of the rate in which the software can be coded. It shows how many hours it takes to create one ESLOC.

- **Quantitative Independent Variables:**
  - **ESLOC**: Source Lines of Code (SLOC) is the delivered size of the product developed, not including any code that was needed to assist development but was not delivered (such as temporary stubs, test scaffoldings, or debug statements). Equivalent Source Lines of Code (ESLOC) is a measure of the program's size, adjusted to account for reuse levels. Mathematically, ESLOC was calculated with the following formula:
  - ESLOC = New Code + 0.05 Reused Code + 0.50 Modified Code
  - Size, as measured by ESLOC, is considered to consistently and reasonably represent the work that must be done. Other commonly used size units include function points and algorithms.
  - **Software Requirements**: The actual number of software requirements. This does not include count requirements concerning external interfaces not under that project's control.
  - **Peak Staff**: This item refers to the actual peak team size, measured in full-time equivalent staff and includes only direct labor.
  - **Productivity (Hours/ESLOC)**: See above. Definition does not change.

- **Dummy Independent Variables:**
  - **Contractor Maturity Rating**: Reports the characterization of the developer's software process maturity using a methodology such as the Software Engineering Institute (SEI) software Capability Maturity Model Integration (CMMI). CMMI is a process improvement model that is based on the principle of achieving continuous improvement through measurement (Defense Acquisition University, 2008). The CMMI provides a framework that is used to measure both the maturity of an organization's software processes as the basis for long-term internal process improvement efforts by the developer and evaluate the developer's software process capability for the purposes of contract award or risk assessment by the acquirer (Defense Acquisition University, 2008).

BACK

Regression Results

Duration = ESLOC						
Database	Equation	Adjusted R^2	Mean	Standard Error	Coefficient of Variation (Fit Space)	Obs
Overall	Hrs = 6.873e+004 + 0.05726 * ESLOC	-0.02%	72,770.47	199,382.44	273.99%	568
Incremental	Hrs = 3.685e+004 + 0.7119 * ESLOC	46.72%	99,119.06	70,894.61	71.52%	90
Sprial	Hrs = 4.562e+004 + 0.0359 * ESLOC	2.06%	49,695.26	84,481.57	170.00%	140
Waterfall	Hrs = 35898 + 0.3278 * ESLOC	25.44%	58,549.11	83,872.29	143.25%	119
Ada	Hrs = (-34255) + 2.141 * ESLOC	56.85%	120,129.25	201,073.29	167.38%	81
C	Hrs = 2.372e+004 + 0.507 * ESLOC	36.68%	66,193.25	89,178.70	134.72%	291
Java	Hrs = (-50558) + 1.606 * ESLOC	93.72%	104,981.83	82,547.30	78.63%	99
Avionics	Hrs = 5.533e+004 + 0.4753 * ESLOC	17.34%	90,215.18	100,253.11	111.13%	32
C4I	Hrs = 1.296e+004 + 0.5464 * ESLOC	21.37%	42,640.65	52,812.11	123.85%	43
Planning	Hrs = (-1.263e+004) + 1.659 * ESLOC	92.30%	73,784.18	47,010.99	63.71%	29
Simulation	Hrs = 57990 + 0.1603 * ESLOC	3.69%	82,848.86	135,201.71	163.19%	22
Training	Hrs = (-21454) + 1.77 * ESLOC	87.23%	44,520.65	29,827.57	67.00%	20
Air Force	Hrs = 32794 + 0.4897 * ESLOC	48.11%	82,052.78	66,075.85	80.53%	74
Army	Hrs = 1.412e+004 + 0.6038 * ESLOC	41.42%	62,212.15	94,404.19	151.75%	277
Navy	Hrs = (-1.717e+004) + 1.565 * ESLOC	69.79%	106,413.49	176,598.70	165.96%	169
BAE	Hrs = 15537 + 0.5101 * ESLOC	29.93%	33,055.15	30,184.73	91.32%	55
Boeing	Hrs = (-53651) + 1.332 * ESLOC	76.38%	255,857.68	259,834.34	101.55%	37
General Dynamics	Hrs = (-3426) + 1.11 * ESLOC	65.47%	48,343.55	59,073.00	122.19%	105
Lockheed Martin	Hrs = 7264 + 0.5217 * ESLOC	48.23%	55,082.13	62,147.02	112.83%	63
Northup Grumman	Hrs = 3.628e+004 + 0.2429 * ESLOC	21.18%	61,446.55	68,096.08	110.82%	91
Raytheon	Hrs = 2.661e+004 + 0.4418 * ESLOC	32.47%	44,073.50	38,539.34	87.44%	124

BACK

Regression Results

Productivity = Peak Staff						
Database	Equation	Adjusted R^2	Mean	Standard Error	Coefficient of Variation (Fit Space)	Obs
Overall	Productivity = 3.072 + (-0.01106) * Peakstaff	-0.17%	2.82	23.23	822.44%	475
Incremental	Productivity = 2.362 + (-0.02111) * Peakstaff	1.80%	1.98	2.05	103.92%	90
Sprial	Productivity = 6.288 + (-0.07778) * Peakstaff	-0.56%	4.58	42.49	928.21%	140
Waterfall	Productivity = 3.771 + (-0.03461) * Peakstaff	0.67%	3.19	5.87	184.30%	95
Ada	Productivity = 3.453 + (-0.03974) * Peakstaff	3.30%	2.66	4.11	154.86%	77
C	Productivity = 3.869 + (-0.01069) * Peakstaff	-0.35%	3.62	31.08	858.25%	264
Java	Productivity = 1.168 + (-0.002139) * Peakstaff	-1.08%	1.11	1.49	134.62%	77
Avionics	Productivity = 3.124 + (-0.02194) * Peakstaff	-2.23%	2.70	4.21	155.92%	32
C4I	Productivity = 1.631 + (-0.04009) * Peakstaff	9.68%	1.11	1.27	114.49%	42
Planning	Productivity = 5.9 + (-0.05403) * Peakstaff	15.45%	3.20	4.00	124.92%	7
Simulation	Productivity = 1.644 + (-0.006277) * Peakstaff	-3.24%	1.52	1.31	86.01%	21
Training	Productivity = 0.6042 + 0.03435 * Peakstaff	11.01%	0.94	0.56	59.60%	20
Air Force	Productivity = 1.431 + (-0.005509) * Peakstaff	-1.10%	1.31	1.73	131.47%	73
Army	Productivity = 3.633 + (-0.01036) * Peakstaff	-0.41%	3.36	33.21	988.05%	229
Navy	Productivity = 3.281 + (-0.02415) * Peakstaff	0.66%	2.88	5.21	180.99%	164
BAE	Productivity = 0.9273 + (-0.002348) * Peakstaff	-4.04%	0.90	0.73	81.21%	26
Boeing	Productivity = 1.028 + 0.0009291 * Peakstaff	-1.55%	1.11	1.00	90.14%	35
General Dynamics	Productivity = 1.446 + (-0.005) * Peakstaff	-1.04%	1.37	1.83	133.43%	77
Lockheed Martin	Productivity = 1.169 + (-0.01115) * Peakstaff	1.95%	0.96	1.20	125.17%	60
Northup Grumman	Productivity = 0.9979 + 8.072e-005 * Peakstaff	-1.51%	1.00	0.76	76.26%	68
Raytheon	Productivity = 3.843 + (-0.04592) * Peakstaff	0.11%	3.28	5.59	170.30%	108

BACK

Summary of Statistical Significance

	Duration = peak staff + ESLOC + productivity	Duration = ESLOC	Duration = Productivity	Productivity = peak staff	Productivity = ESLOC	Productivity = Peak staff + ESLOC	Productivity = Peak staff + SW Requirements	Productivity = ESLOC + CMMI	Productivity = SW Requirements + CMMI	Productivity = Peak Staff + CMMI + ESLOC	Productivity = Peak Staff + CMMI + SW Requirements	Duration = Productivity + SW Requirements	Duration = ESLOC + CMMI	Duration = Productivity + CMMI	Duration = ESLOC + peak staff	Duration =CMMI + ESLOC + Peak Staff	Duration = ESLOC + SW Req + Peak staff	Duration = SW req + CMMI + ESLOC + Peak Staff
Overall	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Incremental	90	90	X	80	90	X	80	X	X	X	X	X	X	X	90	X	X	X
Sprial	X	90	X	X	X	X	X	X	X	X	X	X	X	X	80	X	80	X
Waterfall	X	90	X	X	90	X	X	X	X	X	X	X	X	X	90	X	90	X
Ada	X	90	X	90	80	X	X	X	90	X	X	X	90	X	X	X	X	X
C	X	90	X	X	X	X	X	X	X	X	X	X	80	X	90	X	90	X
Java	80	90	X	X	X	X	X	X	X	X	X	X	90	X	80	X	80	X
Avionics	X	90	80	X	80	X	X	80	90	X	X	90	90	X	X	X	X	X
C4I	90	90	90	90	90	X	80	X	X	X	X	90	90	X	90	80	90	X
Planning	X	90	X	X	X	X	X	90	NA	NA	NA	X	X	90	90	NA	X	NA
Simulation	X	80	NA	X	90	X	X	X	X	X	X	X	X	X	X	X	X	X
Training	90	90	90	90	90	X	X	X	X	80	80	90	90	90	80	X	90	X
Air Force	X	90	X	X	90	X	X	X	X	X	X	80	X	X	90	X	90	X
Army	X	90	X	X	X	X	X	X	X	X	X	X	90	X	90	X	90	X
Navy	90	90	X	80	90	X	X	80	X	X	X	X	X	X	90	90	90	X
BAE	X	90	80	X	90	90	X	80	NA	NA	NA	80	X	80	X	NA	90	NA
Boeing	90	90	X	X	X	X	X	X	X	X	X	X	80	X	90	80	90	80
General Dynamics	X	90	X	X	80	X	X	90	NA	NA	NA	X	X	X	90	NA	80	NA
Lockheed Martin	X	90	X	80	90	X	X	90	X	X	X	X	80	X	X	X	X	X
Northup Grumman	90	90	90	X	80	90	X	NA	NA	NA	NA	90	NA	NA	X	NA	X	NA
Raytheon	X	90	X	X	90	X	X	X	X	X	X	X	X	X	90	X	90	X

Bibliography

- Connolly, T., & Dean, D. (1997). Decomposed Versus Holistic Estimates of Effort Required for Software Writing Tasks. *Management Science* , 1029-1045.
- Defense Acquisition University. (2008, October 7). *Basic Systems Acquisition Management* . 2008, Virginia, USA: Defense Acquisition Workforce Improvement Act.
- Defense Cost Resource Center. (2008, October). Software Resource Data Report Database. Department of Defense.
- Dewberry, C. (2009, August 24). Software CER Documentation. (J. Leotta, Interviewer)
- Hoegl, M., & Georg Gemuenden, H. (2001). Teamwork Quality and the Success of Innovative Projects: A Theoretical Concept and Empirical Evidence. *Organization Science* , 435-449.
- Jensen, R. W., Putnam, L. H., & Roetzheim, W. (2006, February). *Crosstalk, the Journal of Defense Software Engineering*. Retrieved August 25, 2009, from Software Estimating Models: Three Viewpoints:
- http://www.stsc.hill.af.mil/crosstalk/2006/02/0602JensenPutnamRoetzheim.html
- Maxwell, K., & Van Wassenhove, L. (1999). Performance Evaluation of General and Company Specific Models in Software Development Effort Estimating. *Management Science* , 787-803.
- Minkiewicz, A. (2008). *Computer Aid Inc*. Retrieved August 25, 2009, from The Evolution of Software Estimating: www.compaid.com/caiinternet/ezine/Estimating-AM.pdf
- National Aeronautics and Space Administration. (2002, May 17). *Parametric Cost Estimating Handbook*. Retrieved August 23, 2009, from Chapter 5: Software Parametric Cost Estimating: http://cost.jsc.nasa.gov/PCEHHTML/pceh.htm
- Ross, M. A. (2008). Next Generation Software Estimating Framework: 25 Years Later and Thousands of Projects Later. *Society of Cost Estimating and Analysis- International Society of Parametric Analysis* , 7-15.
- Wu, L. (1997, May 4). *University of Calgary*. Retrieved August 25, 2009, from Comparison of the Software Cost Estimating Models: http://www.compapp.dcu.ie/~renaat/ca421/LWu1.html

BACK