The Value of Systems Engineering

What do we know about it?
How do we discover more?

Al Mink
Systems Value / GMU
Value of SE

Overview

1. The Problem

2. What We Know Today

3. The Race to Discover More

4. Conclusions
Value of SE

The Problem (Stakeholder Analysis)

What – and how much – SE is appropriate for a particular system development program?

- Customers
  - Unsure of how to evaluate bids
  - May not receive best value for the systems they acquire
  - DoD #1 SE Issue – “Inconsistent SE Practices across life cycle”

- Industry (System Developers & Integrators)
  - Unsure of what to bid, and later loath to add SE costs

- Associations & Academia
  - Unable to fully satisfy their members and students

- SE professionals
  - Lack rigorous justification for their recommendations
Value of SE
The Problem (IDEF 0 View)

SE produces more than products -- It affects the value of operational system produced

Buede pg 413
Value of SE

The Problem (Pareto View)

SE activity upfront affects entire development

Buede, Figure 1.2
Value of SE

What we know today – Studies & Models

Gruhl, National Avionics and Space Administration (NASA), 1992
   Compared upfront expenditures to eventual cost growth

Herbsleb, Software Engineering Institute (SEI), 1994
   Studied ROI on process improvement in software

Honour, International Council on Systems Engineering (INCOSE), 2002
   Surveyed industry to compare SE Effort to cost & schedule

Boehm & Valerdi, SE ROI (COCOMO), 2006 (Draft)
   Analyzed SE activities from COCOMO II

Valerdi & Boehm, Constructive System Engineering Cost Model
   (COSYSMO), 2004
   Developed parametric estimation model similar to COCOMO

Others…
Value of SE

What we know today – NASA Study

Total Program Overrun
32 NASA Programs

Definition Percent = \frac{\text{Definition $}}{\text{Target + Definition$}}

Definition Percent of Total Estimate

Program Overrun = \frac{\text{Actual + Definition$}}{\text{Target + Definition$}}

Diminishing Returns

R^2 = 0.5206
Value of SE

What we know today – INCOSE Study

SE Effort = SE Quality * SE Cost/Actual Cost

90% Assurance (1.6σ)

Average Cost Overrun

Diminishing Returns

Source: Honour 2004
## Value of SE

**What we know today – ROI of SE**

### SE ROI by Software Size of System

<table>
<thead>
<tr>
<th>KSLOC</th>
<th>Very Low</th>
<th>Low</th>
<th>Nominal</th>
<th>High</th>
<th>Very High</th>
<th>Extra High</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-</td>
<td>52%</td>
<td>-20%</td>
<td>-45%</td>
<td>-58%</td>
<td>-77%</td>
</tr>
<tr>
<td>100</td>
<td>-</td>
<td>248%</td>
<td>80%</td>
<td>18%</td>
<td>-10%</td>
<td>-54%</td>
</tr>
<tr>
<td>1,000</td>
<td>-</td>
<td>512%</td>
<td>204%</td>
<td>91%</td>
<td>42%</td>
<td>-30%</td>
</tr>
<tr>
<td>10,000</td>
<td>-</td>
<td>840%</td>
<td>356%</td>
<td>177%</td>
<td>99%</td>
<td>-4%</td>
</tr>
</tbody>
</table>

*Boehm & Valerdi, 2006*
Value of SE

What we know today – ROI of SE

SE Activities Affect Software Development

Boehm & Valerdi, 2006

Development Cost Increase: Minimal SE compared to Robust SE

Boehm & Valerdi, 2006

Software Product Size (KSLOC)
Value of SE

What we know today – COSYSMO

Limited ability to estimate “effort”

Size
Drivers
Effort
Multipliers

COSYSMO

Person
Months of systems engineering effort

Pred(30) 50% uncalibrated
Pred(30) 70% calibrated

Valerdi, 2005
Value of SE

*What we know today – COSYSMO*

### SE Effort Across ANSI/EIA 632 Fundamental Processes

<table>
<thead>
<tr>
<th>ANSI/EIA 632 Fundamental Process</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition &amp; Supply</td>
<td>7%</td>
<td>3.5</td>
</tr>
<tr>
<td>Technical Management</td>
<td>17%</td>
<td>4.5</td>
</tr>
<tr>
<td>System Design</td>
<td>30%</td>
<td>6.1</td>
</tr>
<tr>
<td>Product Realization</td>
<td>15%</td>
<td>8.7</td>
</tr>
<tr>
<td>Technical Evaluation</td>
<td>31%</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Valerdi & Wheaton 2005
Value of SE

What we know today – COSYSMO

SE Effort Across IOS/IEC 15288 Lifecycles

<table>
<thead>
<tr>
<th>Stage</th>
<th>%Effort</th>
<th>STDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptualize</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>Develop</td>
<td>36%</td>
<td></td>
</tr>
<tr>
<td>Oper Test &amp; Eval</td>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>Transition to Operation</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>Operate, Maintain, or Enhance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replace or Dismantle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Valerdi & Wheaton 2005
Value of SE

What we know today – COSYSMO

SE Effort Across IOS/IEC 15288 Lifecycles

Valerdi & Wheaton 2005
## Value of SE

### What we know today – Summary

<table>
<thead>
<tr>
<th>STUDY</th>
<th>Author &amp; Background</th>
<th>Findings</th>
<th>SE Activities</th>
<th>Definition of Success</th>
<th>Characteristics of Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gruhl (1992)</td>
<td>32 NASA Pgmns</td>
<td>8-15% Upfront Best</td>
<td>First two of five development phases</td>
<td>Cost (Less cost overrun)</td>
<td>Large; Complex; all NASA</td>
</tr>
<tr>
<td>Herbsleb (1994)</td>
<td>13 CMM Companies</td>
<td>Process Improvement ROI 4.0 – 8.8</td>
<td>CMM Process Areas</td>
<td>Cost (Cost reduction through SE investment)</td>
<td>Various; federal contracting</td>
</tr>
<tr>
<td>Honour (2004)</td>
<td>Survey INCOSE SEs</td>
<td>15-20% of project should be SE</td>
<td>Overall SE level of effort (Cost) &amp; related SE quality</td>
<td>Cost &amp; Schedule</td>
<td>Various sizes (measured by total project cost)</td>
</tr>
<tr>
<td>Boehm &amp; Valerdi (2006)</td>
<td>COCOMO II</td>
<td>SE importance grows with project size</td>
<td>COCOMO II RESL (Architecture and Risk)</td>
<td>Cost</td>
<td>Various sizes, but software systems only</td>
</tr>
<tr>
<td>Boehm &amp; Valerdi (2004)</td>
<td>COSYSMO</td>
<td>Estimate within 30% effort 50% - 70% of time</td>
<td>33 activities defined by EIA 632</td>
<td>Cost</td>
<td>Mostly successful projects from federal contractors</td>
</tr>
<tr>
<td>Ancona &amp; Caldwell (1990)</td>
<td>Boundary Management</td>
<td>Managing team boundary 15%; more is better</td>
<td>Team boundary activities – interface between team and external</td>
<td>Product Performance (Successfully marketed products)</td>
<td>Technology products</td>
</tr>
<tr>
<td>Frantz (1995)</td>
<td>Boeing side-by-side projects</td>
<td>More SE yielded better quality &amp; shorter duration</td>
<td>Defined by Frantz</td>
<td>Product Performance &amp; Schedule (Quality of product and duration of project)</td>
<td>Three similar systems for manipulating airframes during assembly</td>
</tr>
</tbody>
</table>
Today we possess a *limited* understanding of the **SE effort** required for **success** of a **project**.

- **8-20% in Aggregate***
- **Large, Complex**
- **Cost, Relative to budget**

* COSYSMO tracks 33 SE activities
Value of SE

The Race to Discover More

Four Separate Efforts Underway
Value of SE

The Race to Discover More

All four should increase our understanding of the **SE effort** required for **success** of a **project**

- **By SE activity**
- **On cost, schedule, & quality**
- **Tailored to project**
Value of SE

The Race to Discover More - Methodology

All Four Appear to Follow a General Approach

1. Form Team
2. Develop Approach
3. Identify Projects
4. Collect Data
5. Analyze Data
6. Publish Results
Value of SE
The Race to Discover More - Methodology

How the pieces fit together

1. Abstract Chart
2. Project Information
3. Data Collection Approach
4. Data Collection
5. Factors - Value of SE
6. Facts Available to SEs
Al Mink

Value of SE - NDIA

Capturing Data – Three Categories

4.1 Measure SE Effort (Activities)

4.2 Measure Success

4.3 Characterize Project
Value of SE

The Race to Discover More – Define SE Activities

Defining “SE Activities” – One View

SE 101

Buede
pg 416
Value of SE

The Race to Discover More – Define SE Activities

Defining “SE Activities” – Many Views

**Fragmented by domain opinions**
- Military – DOD/MOD
- Space - NASA/ESA
- Commercial products
- Aircraft
- Automobiles
- Nuclear waste
- Process engineering
- Tool vendors

**Fragmented by discipline opinions**
- Technical leaders
- System architects
- System analysts
- Requirements engineers
- Operations analysts
- Design engineers

**Fragmented by standards**
- ANSI/EIA-632
- IEEE-1220
- ISO-15288
- CMMI
- MIL-STD-499C

Honour
2005
Value of SE

The Race to Discover More – Define SE Activities

How the Different Efforts Define “SE Effort”

Standards

ANSI/EIA-632
IEEE-1220
ISO/IEC-15288
CMM/CMMI
MIL-STD-499C
Value of SE

Emerging Approaches to Move Forward – Define Other Measures

In addition to defining & measuring SE Effort…

Cost, schedule, & quality

Success factors
- EVMS
- Award Fee
- Requirements Trace
- Others…

Tailored to project

Project characteristics
- Size ($)
- Size (hours)
- Technology
- Complexity
- Others…
Value of SE
The Race to Discover More - Methodology

One Other Difference – Collection Mechanism

4. Data Collection

 Mechanism
Value of SE

The Race to Discover More – Define SE Activities

How the Different Efforts Collect Data

Data Collection Mechanisms

Survey

Interview

Work Shops

Value of SE - NDIA
Value of SE

Conclusions

- **Value of SE**
  - Remains fundamental to furthering SE as a respected discipline

- Four approaches underway to determine SE Value
  - With a fifth – Bob Bruff – on the horizon…

- They share commonalities, but also differ:
  - Differing types of projects
  - Differing SE Activities & Deliverables
  - Differing success factors (cost, schedule, quality, etc.)

- Challenges Remain
  - Useful project data – may not be widely available
  - Four separate projects – what if they report different results?
  - Success may be elusive – “The Shangri-La of ROI” (Sheard 2000)

- Make a difference! Support these approaches
Value of SE
Conclusion

Points of Contact

Al Mink
almink@systemsvalue.com

Sue Rose*
rose@systemsandsoftware.org

Joe Elm
jelm@sei.cmu.edu

Ricardo Valerdi
rvalerdi@mit.edu

Eric Honour
ehonour@hcode.com

* Restricted Participation
Value of SE

Questions?

Al Mink
almink@systemsvvalue.com
571 212-4778