Honourcode, Inc.

Systems Engineering
Return on Investment

SE-ROI Research
Interim Results Aug 09

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- Honourcode, Inc.
- CEDISC (Univ of South Australia)
Agenda

- **Background**
  - Motivation for the topic
  - Quick summary of anecdotal prior works

- **SE-ROI Project**
  - Goals and methodology

- **SE-ROI Research Interim Results**
  - Demographics results
  - Interim correlation results
Background

Concepts: Value of SE

Prior results

- Boeing - Franz data
- IBM – Barker data
- Value of SE 2004 data
- EIA SE Effectiveness Study
- SEROI-COCOMO 2008 data
Heuristic Claim of SE

Better systems engineering leads to:
- Better system quality/value
- Lower cost
- Shorter schedule

Traditional Design

“System Thinking” Design

Not Known: How Much Is Enough?

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Impact of Systems Engineering on Quality and Schedule

- Empirical evidence obtained from three parallel (same time) projects
  - Each developed a complex, robotic Universal Holding Fixture (UHF)
  - Each used a different level of SE
  - Results are compared

<table>
<thead>
<tr>
<th>Trait</th>
<th>UHF1</th>
<th>UHF2</th>
<th>UHF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10’ x 40’</td>
<td>8’ x 50’</td>
<td>6’ x 14’</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.005”</td>
<td>±0.003”</td>
<td>±0.003”</td>
</tr>
<tr>
<td>Contact Sensors</td>
<td>None</td>
<td>57</td>
<td>108</td>
</tr>
<tr>
<td>Vacuum Sensors</td>
<td>1</td>
<td>70</td>
<td>108</td>
</tr>
<tr>
<td>Real-time checks</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Probe contours</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>NC interface</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

...W. Forrest Frantz, Impact of Systems Engineering on Quality and Schedule – Empirical Evidence, Boeing, INCOSE 1995
Impacts

- Use of better SE reduced
  - Overall cycle time
  - Time to create req’s
  - Time to design/produce
  - Time to test

...even in the face of more complex, higher quality systems!


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Systems Engineering Effectiveness

- Study of 8 software product development projects during upgrade of SE processes
- Evaluation by cost and schedule against a standard estimating method.

Costing method applies only to project management, business management, systems engineering, system integration, and delivery into production. Application development costs are not included.

...Barker, Determining Systems Engineering Effectiveness, IBM Commercial Products, CSER 2003
Systems Engineering Effectiveness

**Significant Findings:**

- Impact and complexity provide an effective method to perform parametric costing. *Early parametric costing works.*

- Preliminary data indicates that the use of Systems Engineering will improve project productivity when effectively combined with the Project Management and Test Processes. *Systems engineering improves productivity.*

$\$/Point Averages

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without SE</td>
<td>$1,350/pt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With SE</td>
<td>$944/pt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With SE</td>
<td>$1,454/pt</td>
<td>$1,142/pt</td>
<td>$818/pt</td>
</tr>
</tbody>
</table>

...Barker, *Determining Systems Engineering Effectiveness*, IBM Commercial Products, CSER 2003
Schedule Overrun vs. SE Effort

90% Assurance (1.6σ)

Average Schedule Overrun

SE Effort = SE Quality * SE Cost/Actual Cost

Honour, Understanding the Value of Systems Engineering, INCOSE 2004
Cost Overrun vs. SE Effort

90% Assurance (1.6σ)

Average Cost Overrun

SE Effort = SE Quality * SE Cost/Actual Cost

...Honour, Understanding the Value of Systems Engineering, INCOSE 2004
Effect of SE Activities on Projects

Gamma relationship to project performance

Elm, A Survey of Systems Engineering Effectiveness, NDIA, CMU/SEI 2007
COCOMO II: How Much Architecting is Enough?

- Percent of Project Schedule Devoted to Initial Architecture and Risk Resolution
- Added Schedule Devoted to Rework (COCOMO II RESL factor)
- Total % Added Schedule

Sweet Spot Drivers:
Rapid Change: leftward
High Assurance: rightward

Basis: 161 projects in COCOMO II database since implementation of RESL factor

...Boehm/Valerdi/Honour, *The ROI of Systems Engineering: Some Quantitative Results*, USC/MIT, INCOSE 2007

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SE-ROI Project

Methodology

Industry support
Project Goals

Research objectives

*How Much Is Enough?*

- Find out how much of what type of SE correlates with project success
  - What SE practices are appropriate under what conditions.

- Leading indicators
  - Used during a project to assess the project’s expected future success and risks based on SE practices used.

- Identification of good SE practices
  - Appropriate to generate success under different conditions.

Schedule

- ’05–’07 – Technical structuring and definitions
- Late ’07 – Started data gathering
- Internal reports ’08–’09
- Final reports ’10
SE-ROI Project

Interviews
- Just-completed programs
- Key PM/SE/Admin
- Translate program data into project structure

Desired Results
1. Statistical correlation of SE practices with project success
2. Leading indicators
3. Identification of good SE practices

Program characterization
- Program success data
- SE data (hours, quality, methods)

Statistical correlation

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Company Participation

- Data gathering – *minimal impact*
  - Select 2 to 4 programs
  - One day of interviews
  - 2-hour sessions with PM+SE of each program
  - Strong protection of proprietary data

- Reports – *effective program benchmarking*
  - Benchmark report within 30 days of session
    - Compares your programs against prior data
  - Quarterly reports from all prior data, all sources
    - *Correlations found*
    - *Leading indicators proven*
    - *SE practices proven*
Current Status – August 2009

- **SE ontology** from SE standards – wide-spread, acceptable terminology  
  - Completed Oct 05

- **Develop interest base** from possible interview sources (currently ~65)  
  - Completed, Ongoing

- **Create interview data sheets** and vet them through sample interviews  
  - Completed, Oct 06

- **Start program interviews**

- **Gather data** from 40+ programs  
  - Interviews held  
  - Programs ready for interview  
  - Active program contacts  
  - Other known possibilities  
  - **Report benchmark results** to participating organizations  
  - Other known possibilities  
  - **Public reports** on research results  
  - In process

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SE-ROI Research Interim Results

Demographics
Continued additions to “Value of SE” results
Histograms of SE activities
Indications about effectiveness of SE activities
# Basic Demographics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ValueSE Data Set</th>
<th>SE-ROI Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of organizations</td>
<td>Unknown</td>
<td>12</td>
</tr>
<tr>
<td>Number of data points</td>
<td>44</td>
<td>34</td>
</tr>
<tr>
<td>Funding method</td>
<td>Unknown</td>
<td>24 contracted, 10 amortized</td>
</tr>
<tr>
<td>Program total cost</td>
<td>$1.1M - $5.6B Median $42.5M</td>
<td>$600K - $1.8B Median $12.0M</td>
</tr>
<tr>
<td>Cost compliance</td>
<td>(0.8):1 - (3.0):1 Median (1.2):1</td>
<td>(0.6):1 - (10):1 Median (1.0):1</td>
</tr>
<tr>
<td>Development schedule</td>
<td>2.8 mo. - 144 mo. Median 43 mo.</td>
<td>2 mo. - 120 mo. Median 32 mo.</td>
</tr>
<tr>
<td>Schedule compliance</td>
<td>(0.8):1 - (4.0):1 Median (1.2):1</td>
<td>(0.3):1 - (2.5):1 Median (1.0):1</td>
</tr>
<tr>
<td>Percent of program used in systems engineering effort, by cost</td>
<td>0.1% - 27% Median 5.8%</td>
<td>4% - 80% Median 14.8%</td>
</tr>
<tr>
<td>Subjective assessment of systems engineering quality (1 poor to 10 world class)</td>
<td>Values of 1 to 10 Median 5</td>
<td>Values of 1 to 9 Median 7</td>
</tr>
</tbody>
</table>
Program “Size”
Program/Team Parameters

Reqs Understanding

Reqs Volatility

System Complexity

Technology Risk

Stakeholder Team Cohesion

Process Capability
Schedule vs. SE Effort

SE Effort = SE Quality * SE Cost/Actual Cost

R² = 0.2519

Caution: This is interim data.
Cost vs. SE Effort

SE Effort = SE Quality * SE Cost/Actual Cost

R² = 0.323

Caution: This is interim data.
Breakout by SE Activities

- MD: Mission/Purpose Definition
- RE: Requirements Engineering
- SA: System Architecting
- SI: System Implementation
- TA: Technical Analysis
- TM: Technical Leadership/Management
- SM: Scope Management
- VV: Verification & Validation

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Caution: This is interim data.
Typical Data:
Schedule vs. Tech Lead’ship/Mgmt

Proprietary data in chart has been removed.

Chart shows strong visual trend that greater Technical Leadership/Management correlates with lower Schedule overrun.

Weaker visual correlation observed for:
- MD Mission Definition

Strong visual correlation observed for:
- ALL other activities

Caution: This is interim data, not yet reviewed and not ready for release.
**Typical Data:**

**Cost vs. Verif/Valid**

Chart shows strong visual trend that greater Verification/Validation correlates with lower Cost overrun.

Proprietary data in chart has been removed.

Weaker visual correlation observed for:
- MD  Mission Definition

Strong visual correlation observed for:
- RE  Requirements Engineering
- SA  System Architecting
- TA  Technical Analysis
- TM  Technical Leadership/Management
- SM  Scope Management
- VV  Verification & Validation

Caution: This is interim data, not yet reviewed and not ready for release.
Typical Data:

Overall Success vs. Req. Engr

- Proprietary data in chart has been removed.
- Chart shows strong visual trend that greater Requirements Engineering correlates with better Overall Success.

RE Effort = RE Quality * RE Cost/Actual Cost

- Weak visual correlation observed for:
  - None

- Strong visual correlation observed for:
  - MD Mission Definition
  - RE Requirements Engineering
  - SA System Architecting
  - TA Technical Analysis
  - SM Scope Management
  - TM Technical Leadership/Management
  - VV Verification/Validation

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Caution: This is interim data, not yet reviewed and not ready for release.
Typical Data: Tech Quality vs. Reqs Engr

"Technical Quality" is based on compliance with KPP thresholds and goals.

1.0 = Met thresholds
2.0 = Met goals
0.0 = Failed to meet

Proprietary data in chart has been removed.

Chart shows wide scatter, with a very weak trend that greater Requirements Engineering correlates with a tendency to meet threshold.

RE Effort = RE Quality * RE Cost/Actual Cost

Weaker visual correlation observed for: RE Requirements Engineering

Strong visual correlation observed for: TA Technical Analysis

Correlation is toward threshold compliance versus goals. Perhaps calls into question lack of design or contractual emphasis on KPPs?

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Caution: This is interim data, not yet reviewed and not ready for release.
**Effect of SE Activities**

**Which activities correlate to better quality?**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost</th>
<th>Schedule</th>
<th>Overall</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missn Defn^2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reqs Engr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys Arch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys Impl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tech Anlysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tech Mgmt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope Mgmt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ver &amp; Val</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proprietary data in chart has been removed.

Chart shows that nearly all systems engineering activities lead to better cost control, better schedule control, and better overall quality. Technical quality (as defined by KPP compliance) shows little correlation with most SE activities.

^1 Projects aim at requirements compliance rather than goals

^2 For most projects, MD was performed in an earlier phase

Caution: This is interim data, not yet reviewed and not ready for release.
Company Participation

- **Data gathering** – *minimal impact*
  - Select 2 to 4 programs
  - One day of interviews
  - 2-hour sessions with PM+SE of each program
  - Strong protection of proprietary data

- **Reports** – *effective program benchmarking*
  - Benchmark report within 30 days of session
    - Compares your programs against prior data
  - Quarterly reports from all prior data, all sources
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    - *SE practices proven*
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Questions?

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Backup Slides
SE-ROI Project

- Samples of SE-ROI interview data sheets
- Data security
**Program Characterization**

**GRADED QUANTITIES** – Enter three specific numeric values for each.

<table>
<thead>
<tr>
<th></th>
<th>EASY</th>
<th>NOMINAL</th>
<th>DIFFICULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of system requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of system interfaces (external)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of algorithms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of operational scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**OTHER QUANTITIES** – Enter a specific numeric value for each.

<table>
<thead>
<tr>
<th>Number</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of unique components* in the system design</td>
<td>Number of developing organizations*</td>
</tr>
<tr>
<td>Number of unique components* designed as part of the programme</td>
<td>Number of customer agencies* actively involved in the programme</td>
</tr>
<tr>
<td>Number of components* integrated per system (multiple instances count)</td>
<td>System production quantity under this programme</td>
</tr>
<tr>
<td>Number of documented trade studies* at the system level</td>
<td>Number of installation locations</td>
</tr>
<tr>
<td>Number of formal tests* at the system level</td>
<td>CMMI level of parent organization (prime developer only)</td>
</tr>
<tr>
<td>Number of formal test locations* at the system</td>
<td></td>
</tr>
</tbody>
</table>
## Subjective Parameters

### SUBJECTIVE PARAMETERS - Evaluate each parameter on the scale given

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VL</th>
<th>L</th>
<th>N</th>
<th>H</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission/purpose understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements volatility (changes to requirements)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements growth (additions to requirements)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Architecture understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall system complexity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of service requirements (environmental, safety, security, reliability, maintainability, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migration complexity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology risk</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Documentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number and diversity of installations/platforms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of recursive levels in the design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stakeholder team cohesion</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Personnel/team capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel experience/continuity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead system engineer experience level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Program Success

### Programme Success Measures (Cost/Schedule/Technical)

<table>
<thead>
<tr>
<th></th>
<th>Original planned cost ($ Total)</th>
<th>Original planned schedule (Months)</th>
<th>Original planned labor (Person-hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current projected cost ($ Total)</td>
<td>Current projected schedule (Months)</td>
<td>Current projected labor (Person-hrs)</td>
<td></td>
</tr>
<tr>
<td>Current cost expended ($ at time of interview)</td>
<td>Current schedule expended (Months after programme start)</td>
<td>Current schedule labor (Person-hrs)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Performance Parameter* (List the top 4 to 8)</th>
<th>Weight %</th>
<th>Threshold Value*</th>
<th>Goal Value*</th>
<th>Projected Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Stakeholder Success Measures

- **Amortized development** – developer creates system product for a defined market segment
  - Projected return on investment (%)
  - Projected period of return (Months after programme start)

- **Contracted development** – customer creates contractual relationship with the developer
  - Projected contract profit (% of cost)
## Systems Engineering

2. **REQUIREMENTS ENGINEERING**

### METHODS – REQUIREMENTS ENGINEERING
What methods were used to perform requirements engineering? How well did they succeed?

<table>
<thead>
<tr>
<th>TOTAL EFFORT (PERSON-HR)</th>
<th>TOTAL COSTS ($)</th>
<th>QUALITY OF EFFORT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>YL L N H VH</td>
</tr>
</tbody>
</table>

### TOOLS – REQUIREMENTS ENGINEERING
What tools were used to perform requirements engineering? How well did they succeed?

### METRICS – REQUIREMENTS ENGINEERING
List any metrics used to evaluate the requirements engineering. Include the current value of each metric.
Proprietary data agreements with participating companies

Public data is statistical in nature, selected to protect sources

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