Quantifying the Effectiveness of Systems Engineering

Presenters: Joseph P. Elm

The Software Engineering Institute (SEI)
a DoD Research FFRDC
The Software Engineering Institute (SEI)

Who we are

• A Federally Funded Research and Development Center (FFRDC)
• Sponsored by the Department of Defense
  – but we work for all government agencies
• Created in 1984 / CERT program founded in 1988
• A Part of Carnegie Mellon University

What we do

• Software Engineering
• Software Research
• Cybersecurity
• Assurance
• Acquisition Solutions
• Emerging Technologies

Our Mission

To advance the technologies and practices needed to acquire, develop, operate, and sustain software systems that are innovative, affordable, trustworthy, and enduring.
# SEI R&D Technical Priorities and Goals

<table>
<thead>
<tr>
<th>Major Areas</th>
<th>SEI Technical Priorities</th>
<th>Goals Include . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Engineering</td>
<td>Development methods, empirical analysis methods, cost estimation, validation, sustainment</td>
<td>Create and sustain affordable, trustworthy, effective and enduring software systems with acceptable urgency</td>
</tr>
<tr>
<td>Assurance</td>
<td>Designed-in security, evidence, acquisition guidance, tools</td>
<td>Improve the level of assurance in software systems using evidence</td>
</tr>
<tr>
<td>Specific Capabilities</td>
<td>Algorithms, networks and networking, mobile applications, embedded/real-time distributed systems</td>
<td>Maintain and expand the toolbox of techniques in critical, emerging and pervasive areas</td>
</tr>
<tr>
<td>Cybersecurity</td>
<td>Forensics, coding standards, insider threat behavior, malware and code analysis, workforce education</td>
<td>Improve base and operational security, understand adversaries, spreading cyber competence</td>
</tr>
</tbody>
</table>
What does it take to develop a complex system?

Many Systems
- Propulsion
- Hydraulics
- Power
- Controls
- Radar
- Structures
- Navigation
- Computers
- Communications
- ...

Many disciplines
- Mechanical Engineering
  - fluidodynamics
  - structural
- Metallurgical Engineering
- Electrical Engineering
  - power
  - radar
- Communications
- Manufacturing Engineering
- Software Engineering
- Test Engineering
- ...

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But, Not Everything Fits Cleanly into One Discipline

Requirements Development and Management

• Decomposition of requirements
• Allocation of requirements among multiple systems

Interdisciplinary Trade Studies

• Requirements implementation in hardware vs. software
• Exotic alloys for low weight vs. more common materials for low cost
• Lower radar cross section vs. higher aerodynamic performance

Architecture Development

• Model Driven Design
• Quality Attribute Driven Architecture
Who Pulls it All Together?

The Systems Engineer

Required skills
• Global system-wide perspective
• Full life-cycle perspective
• Forward-looking
• Multidisciplinary technical knowledge
• Fact-based decision-making
• Multi-tasking

Tasks Performed *
• Requirements Development
• Requirements Management
• Trade Studies
• System Architecture Development
• Interface Management
• Configuration Management
• Program Planning
• Program Monitoring and Control
• Risk Management
• Product Integration Planning and Oversight
• Verification Planning and Oversight
• Validation Planning and Oversight

How likely is program success if these activities are not done well?

* Some tasks are done in partnership with the Program Manager
Challenges in DoD Acquisition

GAO-09-362T - Actions Needed to Overcome Long-standing Challenges with Weapon Systems Acquisition and Service Contract Management

- “costs … increased 26% and development costs increased by 40% from first estimates”
- “programs … failed to deliver capabilities when promised —often forcing warfighters to [maintain] legacy systems”
- “current programs experienced, on average, a 21-month delay in delivering initial capabilities to the warfighter”

Although DoD is the largest acquirer in the world, acquisition troubles remain ¹

- 2011 MDAP RDT&E cost growth (mean) 84%
- 2011 MDAP Procurement cost growth (mean) 28%
- Effectiveness (1984-2011) 89%
- Suitability (1984-2011) 72%
- Nunn-McCurdy breach rate from 1997-2011 31%

¹ “Performance of the Defense Acquisition System 2013 Annual Report” Table 2-3, page 34
# Root Cause of Poor Program Performance

## Inadequate Systems Engineering!

- Finding from *Performance of the Defense Acquisition System 2013 Annual Report*
  - **Dominant root cause** of MDAP Cost Growth
- Finding from GAO-09-362T
  - “... managers rely heavily on assumptions about system requirements, technology, and design maturity, which are consistently too optimistic. These gaps are largely the result of a **lack of a disciplined systems engineering analysis** prior to beginning system development …”

### MDAP Cost Growth: PARCA Root Cause Analysis

<table>
<thead>
<tr>
<th>Dominant</th>
<th>Count</th>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor management performance</td>
<td>10</td>
<td>56%</td>
<td>Systems engineering, Contractual incentives, Risk management, Situational Awareness</td>
</tr>
<tr>
<td>Baseline cost and schedule estimates</td>
<td>5</td>
<td>28%</td>
<td>Framing assumptions</td>
</tr>
<tr>
<td>Change in procurement quantity</td>
<td>4</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrequent</th>
<th>Count</th>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature technology, excessive manufacturing, or integration risk</td>
<td>1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Unrealistic performance expectations</td>
<td>2</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Unanticipated design, engineering, manufacturing or technology issues</td>
<td>1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Funding inadequacy</td>
<td>None</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. “*Performance of the Defense Acquisition System 2013 Annual Report*” Table 2-3, page 34
Perceptions of SE

The SE efforts on my program are critical because they …

… pay off in the end.

… ensure that stakeholder requirements are identified and addressed.

… provide a way to manage program risks.

… establish the foundation for all other aspects of the design.

… optimize the design through evaluation of alternate solutions.

We need to minimize the SE efforts on this program because …

… including SE costs in our bid will make it non-competitive.

… we don’t have time for ‘paralysis by analysis.’ We need to get the design started.

… we don’t have the budget or the people to support these efforts.

… SE doesn’t produce deliverable outputs.

… our customer won’t pay for them.

These are the ASSERTIONS, but what are the FACTS?
What is the ROI for SE?

It’s difficult to justify the costs of SE in terms that program managers and corporate managers can relate to.

- The costs of SE are evident
  - Cost of resources
  - Schedule time
- The benefits are less obvious and less tangible
  - Cost avoidance (e.g., reduction of rework from interface mismatches)
  - Risk avoidance (e.g., early risk identification and mitigation)
  - Improved efficiency (e.g., clearer organizational boundaries and interfaces)
  - Better products (e.g., better understanding and satisfaction of stakeholder needs)

We need to quantify the effectiveness and value of SE by examining its effect on program performance?
Measuring ROI

Obtain quantitative evidence of the costs and associated benefits of Systems Engineering activities via a survey of development programs.
The SE Effectiveness Study

Purpose

• Strengthen the business case for SE by relating program performance to the use of SE practices.

Method

• Contact development programs using the resources of NDIA, AESS, and INCOSE.
• Survey programs to assess their
  – SE activities
  – Program performance
  – Degree of challenge
• Process responses to identify statistical relationships between parameters.

Survey Tenets

• All data is submitted anonymously and handled confidentially by the SEI.
• Only aggregated non-attributable data is released.
Articfact-based assessment of SE Practices

Survey content is based on a recognized standard (CMMI)
Assessment of Program Performance

Assess TOTAL Program Performance

• Program Cost, Program Schedule, Technical Performance
• Focus on commonly used measurements
  – EVMS, baseline management
  – requirements satisfaction
  – budget re-baselining and growth
  – milestone and delivery satisfaction

Assessment of Other Factors

• Program Challenge – some programs are more complex than others
• Prior Experience – some acquirers are more capable than others
Study Participants

Participant Solicitation

- Contacted key members of major defense contractors to promote study participation
- Contacted the memberships of NDIA SE Division, IEEE AESS, and INCOSE

Collected 148 valid responses

Which of these best describes your industry or service?

- 116: Ind. Mfg & Svc: defense
- 7: Ind. Mfg & Svc: Electronic...
- 2: Ind. Mfg and Svc: Other
- 2: Transportation
- 0: Energy
- 9: Communications
- 0: Consumer Goods & Svc
- 1: Health Care
- 10: Other

Please enter the country in which most of the design and development engineering will be/was performed.

- 130: USA
- 6: UK
- 3: South Africa
- 2: Australia
- 2: Other
- 1: Canada
- 1: India
- 1: The Netherlands
- 1: Sweden
- 1: Finland
Study Results

Total program contract value:
- Mean: $488 M$
- Std. Dev.: $2.22 B$
- Median: $50.5 M$

Program Performance (Perf):
- Median (2nd quartile): 3.58
- 1st quartile: 3.03
- 3rd quartile: 3.98

Program Challenge (PC):
- Median (2nd quartile): 2.50
- 1st quartile: 2.22
- 3rd quartile: 2.68

Total SE Deployed on Program (SEC_Total):
- Median (2nd quartile): 2.78
- 1st quartile: 2.08
- 3rd quartile: 3.41
The Bottom Line: \( \text{SE} = \text{Performance} \)

Across ALL programs, 1/3 are at each performance level

For Lower SEC programs, only 15\% deliver higher performance

For Middle SEC programs, 24\% deliver higher performance

For Higher SEC programs, 57\% deliver higher performance

\[ \text{Gamma} = 0.49 \quad \text{p-value} < 0.001 \]
For Challenging Programs
SE is even MORE important

Perf vs. SEC_Total (Low PC)

<table>
<thead>
<tr>
<th>SEC Level</th>
<th>Lower SEC (n=22)</th>
<th>Middle SEC (n=26)</th>
<th>Higher SEC (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perf</td>
<td>45%</td>
<td>58%</td>
<td>36%</td>
</tr>
<tr>
<td>SEC</td>
<td>32%</td>
<td>19%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Gamma = 0.34       p-value = 0.029

A STRONG relationship between Total SE and Program Performance for LOWER CHALLENGE programs

Perf vs. SEC_Total (High PC)

<table>
<thead>
<tr>
<th>SEC Level</th>
<th>Lower SEC (n=26)</th>
<th>Middle SEC (n=23)</th>
<th>Higher SEC (n=26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perf</td>
<td>69%</td>
<td>39%</td>
<td>12%</td>
</tr>
<tr>
<td>SEC</td>
<td>8%</td>
<td>23%</td>
<td>26%</td>
</tr>
</tbody>
</table>

Gamma = 0.62       p-value = 0.000

A VERY STRONG relationship between Total SE and Program Performance for HIGHER CHALLENGE programs
A Deeper Look at SE Activities

Our survey questions addressed 11 areas of SE Activities

- Program Planning
- Requirements Development and Management
- Product Architecture
- Trade Studies
- Product Integration
- Verification
- Validation
- Risk Management
- Configuration Management
- Integrated Product Teams
- Program Monitoring and Control

This enabled us to assess a program’s deployment of SE in each of these areas
Early SE is the MOST Important

Perf vs. EarlySE

<table>
<thead>
<tr>
<th>Lower Early SE</th>
<th>Middle Early SE</th>
<th>Higher Early SE</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>12% (n=31)</td>
<td>34% (n=23)</td>
<td>48% (n=21)</td>
<td>68%</td>
</tr>
<tr>
<td>54%</td>
<td>28%</td>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>

Gamma = 0.53

The relationship:
for the set of all programs 0.53 = Very Strong
for the set of Low Challenge programs 0.25 = Moderate
for the set of High Challenge programs 0.69 = Very Strong

Perf vs. EarlySE (Low PC)

<table>
<thead>
<tr>
<th>Lower Early SE</th>
<th>Middle Early SE</th>
<th>Higher Early SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>21% (n=19)</td>
<td>30% (n=30)</td>
<td>46% (n=24)</td>
</tr>
<tr>
<td>47%</td>
<td>53%</td>
<td>38%</td>
</tr>
</tbody>
</table>

Gamma = 0.25

Perf vs. EarlySE (High PC)

<table>
<thead>
<tr>
<th>Lower Early SE</th>
<th>Middle Early SE</th>
<th>Higher Early SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>26% (n=31)</td>
<td>35% (n=23)</td>
<td>67% (n=21)</td>
</tr>
<tr>
<td>68%</td>
<td>43%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Gamma = 0.69
Program Planning vs. Performance

Perf vs. SEC-PP

The relationship:
for the set of all programs $\gamma = 0.46 = \text{Very Strong}$
for the set of Low Challenge programs $\gamma = 0.16 = \text{Weak}$
for the set of High Challenge programs $\gamma = 0.65 = \text{Very Strong}$
Requirements Dev’t & Mg’t vs. Performance

Perf vs. SEC-REQ

The relationship:
for the set of all programs \(0.44 = \text{Very Strong}\)
for the set of Low Challenge programs \(0.36 = \text{Strong}\)
for the set of High Challenge programs \(0.50 = \text{Very Strong}\)
Verification vs. Performance

**Perf vs. SEC-VER**

The relationship:
- for the set of all programs: $0.43 = \text{Very Strong}$
- for the set of Low Challenge programs: $0.27 = \text{Moderate}$
- for the set of High Challenge programs: $0.60 = \text{Very Strong}$
Architecture vs. Performance

Perf vs. SEC-ARCH

<table>
<thead>
<tr>
<th>Lower SEC (n=45)</th>
<th>Middle SEC (n=54)</th>
<th>Higher SEC (n=49)</th>
<th>All</th>
</tr>
</thead>
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<tr>
<td>16%</td>
<td>31%</td>
<td>49%</td>
<td>Higher Perf</td>
</tr>
<tr>
<td>49%</td>
<td>35%</td>
<td>33%</td>
<td>Middle Perf</td>
</tr>
<tr>
<td>36%</td>
<td>36%</td>
<td>18%</td>
<td>Lower Perf</td>
</tr>
</tbody>
</table>

Gamma = 0.41  p-value = 0.000

The relationship:
for the set of all programs  0.41 = Very Strong
for the set of Low Challenge programs  0.31 = Strong
for the set of High Challenge programs  0.49 = Very Strong

Perf vs. SEC-ARCH (Low PC)

<table>
<thead>
<tr>
<th>Lower SEC (n=21)</th>
<th>Middle SEC (n=28)</th>
<th>Higher SEC (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24%</td>
<td>43%</td>
<td>46%</td>
</tr>
<tr>
<td>43%</td>
<td>50%</td>
<td>46%</td>
</tr>
<tr>
<td>21%</td>
<td>8%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Gamma = 0.31  p-value = 0.051

Perf vs. SEC-ARCH (High PC)

<table>
<thead>
<tr>
<th>Lower SEC (n=24)</th>
<th>Middle SEC (n=26)</th>
<th>Higher SEC (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8%</td>
<td>29%</td>
<td>52%</td>
</tr>
<tr>
<td>63%</td>
<td>46%</td>
<td>20%</td>
</tr>
<tr>
<td>19%</td>
<td>28%</td>
<td></td>
</tr>
</tbody>
</table>

Gamma = 0.49  p-value = 0.001
Summary of Relationships – All Projects

Performance vs. SE Capability - All Projects

-0.3  -0.2  -0.1  0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7

Total SE
Early SE
Project Planning
Req'ts Dev't & Mg't
Verification
Product Architecture
Configuration Mg't
Trade Studies
Monitor & Control
Validation
Product Integration
Risk Management
Integ. Product Teams
Project Challenge
Prior Experience

Moderate  Weak  Moderate  Strong  Very Strong

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Summary of Relationships - Challenging Projects

Performance vs. SE Capability - High Challenge

- Total SE
- Early SE
- Project Planning
- Verification
- Configuration Mg't
- Monitor & Control
- Req'ts Dev't & Mg't
- Product Architecture
- Validation
- Trade Studies
- Product Integration
- Integ. Product Teams
- Risk Management
- Project Challenge
- Prior Experience

Moderate  Weak  Moderate  Strong  Very Strong
Comparison with 2007 SE Effectiveness Study

On the whole, relationships identified in this study are noticeably stronger than those from the previous study

- Probably due to reduction in noise resulting from the larger sample size

Most results from the two studies are generally in agreement
Using the Findings of This Study

System Developers can use this report to:

• plan SE capability improvement efforts focusing on those SE activities most strongly associated with improved program performance
• serve as an industry benchmark for their organization’s SE performance.
  – Assess programs within the organization and compare with the study results to leverage strengths, and improve weaknesses
• justify and defend SE activities applied to programs.

System Acquirers may use this report to:

• incorporate SE requirements into RFPs and source selection activities
  – Ensure that SE activities are included in schedules and budgets
  – Demand SE deliverables (e.g. SE Management Plan) during program execution
  – Require SE evaluations of contractors during source selection and during program execution
• employ this survey or similar methods to collect data from during program execution as a means of identifying supplier SE deficiencies contributing to program risks.
Using the Findings of This Study

SE Educators may use this report to:
- Focus curricula on key aspects of SE
- Convey to students the value of SE

All may use this report to:
- identify critical SE capabilities to guide Workforce Development
Defense vs. Non-defense Projects

The data from the 2012 SE Effectiveness Study included responses from both defense-domain and non-defense-domain projects

- Cross-domain comparison of SE deployment, project performance and the relationships between them can identify improvement opportunities through transplantation of best practices between domains

SYSTEMS ENGINEERING DEPLOYMENT

PROJECT PERFORMANCE
Defense vs. Non-defense Projects

Next Steps: Investigate the differences between SE deployment / effectiveness in defense and non-defense domains to find “transplantable” best practices.
Next Steps

Download the 2012 SE Effectiveness reports from the SEI website

http://www.sei.cmu.edu/measurement/research/acquisition/Business-Case-SE.cfm

- The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey
- The Business Case for Systems Engineering Study: Detailed Response Data
- The Business Case for Systems Engineering Study: Assessing Project Performance from Sparse Data

Search for ways to apply the findings within your own work and your own organization.

Contact the SEI with questions or to obtain assistance.
For more information, contact

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1-888-201-4479

OR

Joseph P. Elm
jelm@sei.cmu.edu
412-268-9132


Integrated Product Teams vs. Performance

The relationship:
- for the set of all programs: $\gamma = 0.18$ = Weak
- for the set of Low Challenge programs: $\gamma = -0.12$ = Weak Neg.
- for the set of High Challenge programs: $\gamma = 0.40$ = Strong

**Perf vs. SEC-IPT**

<table>
<thead>
<tr>
<th>SEC Category</th>
<th>Lower Perf</th>
<th>Middle Perf</th>
<th>Higher Perf</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower SEC (n=51)</td>
<td>37%</td>
<td>31%</td>
<td>31%</td>
<td>37%</td>
</tr>
<tr>
<td>Middle SEC (n=52)</td>
<td>41%</td>
<td>35%</td>
<td>27%</td>
<td>35%</td>
</tr>
<tr>
<td>Higher SEC (n=45)</td>
<td>22%</td>
<td>42%</td>
<td>41%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Gamma = 0.18, p-value = 0.101

**Perf vs. SEC-IPT (Low PC)**

<table>
<thead>
<tr>
<th>SEC Category</th>
<th>Lower Perf</th>
<th>Middle Perf</th>
<th>Higher Perf</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower SEC (n=23)</td>
<td>13%</td>
<td>23%</td>
<td>25%</td>
<td>14%</td>
</tr>
<tr>
<td>Middle SEC (n=26)</td>
<td>30%</td>
<td>38%</td>
<td>46%</td>
<td>31%</td>
</tr>
<tr>
<td>Higher SEC (n=24)</td>
<td>57%</td>
<td>29%</td>
<td>5%</td>
<td>31%</td>
</tr>
</tbody>
</table>

Gamma = -0.12, p-value = 0.436

**Perf vs. SEC-IPT (High PC)**

<table>
<thead>
<tr>
<th>SEC Category</th>
<th>Lower Perf</th>
<th>Middle Perf</th>
<th>Higher Perf</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower SEC (n=28)</td>
<td>14%</td>
<td>29%</td>
<td>31%</td>
<td>16%</td>
</tr>
<tr>
<td>Middle SEC (n=26)</td>
<td>57%</td>
<td>38%</td>
<td>57%</td>
<td>28%</td>
</tr>
<tr>
<td>Higher SEC (n=21)</td>
<td>31%</td>
<td>38%</td>
<td>31%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Gamma = 0.4, p-value = 0.007
Risk Management vs. Performance

Perf vs. SEC-RSKM

The relationship:
- for the set of all programs: $0.21 = \text{Moderate}$
- for the set of Low Challenge programs: $0.18 = \text{Weak}$
- for the set of High Challenge programs: $0.24 = \text{Moderate}$
Trade Studies vs. Performance

**Perf vs. SEC-TRD**

- Lower SEC (n=46): 
  - Lower Perf: 13%
  - Middle Perf: 33%
  - Higher Perf: 52%

- Middle SEC (n=58): 
  - Lower Perf: 43%
  - Middle Perf: 34%
  - Higher Perf: 25%

- Higher SEC (n=44): 
  - Lower Perf: 43%
  - Middle Perf: 33%
  - Higher Perf: 23%

**Perf vs. SEC-TRD (Low PC)**

- Lower SEC (n=19): 
  - Lower Perf: 11%
  - Middle Perf: 33%
  - Higher Perf: 50%

- Middle SEC (n=30): 
  - Lower Perf: 26%
  - Middle Perf: 50%
  - Higher Perf: 29%

- Higher SEC (n=24): 
  - Lower Perf: 26%
  - Middle Perf: 17%
  - Higher Perf: 21%

**Perf vs. SEC-TRD (High PC)**

- Lower SEC (n=27): 
  - Lower Perf: 15%
  - Middle Perf: 32%
  - Higher Perf: 55%

- Middle SEC (n=28): 
  - Lower Perf: 56%
  - Middle Perf: 50%
  - Higher Perf: 20%

- Higher SEC (n=20): 
  - Lower Perf: 56%
  - Middle Perf: 50%
  - Higher Perf: 25%

**The relationship:**

- for the set of all programs: \(\gamma = 0.38\) = **Strong**
- for the set of Low Challenge programs: \(\gamma = 0.29\) = **Moderate**
- for the set of High Challenge programs: \(\gamma = 0.43\) = **Very Strong**
Validation vs. Performance

Perf vs. SEC-VAL

The relationship:
- for the set of all programs: $\Gamma = 0.33 = \text{Strong}$
- for the set of Low Challenge programs: $\Gamma = 0.23 = \text{Moderate}$
- for the set of High Challenge programs: $\Gamma = 0.48 = \text{Very Strong}$
Product Integration vs. Performance

Perf vs. SEC-PI

The relationship:
for the set of all programs \(0.33 = \text{Strong}\)
for the set of Low Challenge programs \(0.23 = \text{Moderate}\)
for the set of High Challenge programs \(0.42 = \text{Very Strong}\)

Perf vs. SEC-PI (Low PC)

Perf vs. SEC-PI (High PC)
Configuration Management vs. Performance

Perf vs. SEC-CM

The relationship:
for the set of all programs \( \gamma = 0.38 \) = Strong
for the set of Low Challenge programs \( \gamma = 0.22 \) = Moderate
for the set of High Challenge programs \( \gamma = 0.53 \) = Very Strong

Perf vs. SEC-CM (Low PC)

Gamma = 0.22 p-value = 0.203

Perf vs. SEC-CM (High PC)

Gamma = 0.53 p-value = 0

Quantifying the Effectiveness of SE
01-Oct-2014
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Program Monitoring & Control vs. Performance

Perf vs. SEC-PMC

The relationship:
- for the set of all programs: $0.38 = \text{Strong}$
- for the set of Low Challenge programs: $0.27 = \text{Moderate}$
- for the set of High Challenge programs: $0.53 = \text{Very Strong}$