Software Engineering Institute | Carnegie Mellon

Building a Business Case for Systems Engineering: the 2012 SE Effectiveness Study

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What does it take to build a complex weapon system?

Many Systems

- Propulsion
- Hydraulics
- EW
- Power
- Controls
- Radar
- Structures
- Navigation
- Computers
- Communications
- …

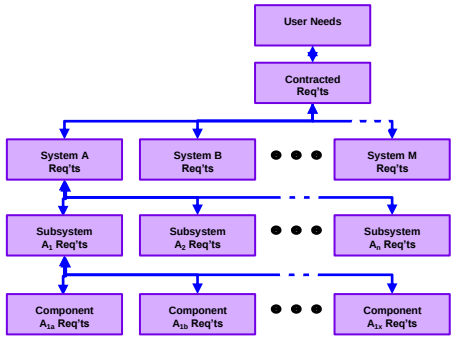
Many disciplines

- Mechanical Engineering – fluidynamics
- Metallurgical Engineering
- Electrical Engineering – power
- Manufacturing Engineering
- Software Engineering
- Electrical Engineering – radar
- Mechanical Engineering – structural
- Electrical Engineering - Communications
- Test Engineering
- …

But, Not Everything Fits Cleanly into One Discipline

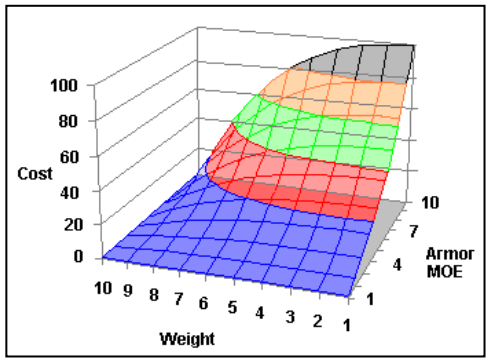
Requirements Development and Management

- Decomposition of requirements
- Allocation of requirements among multiple systems



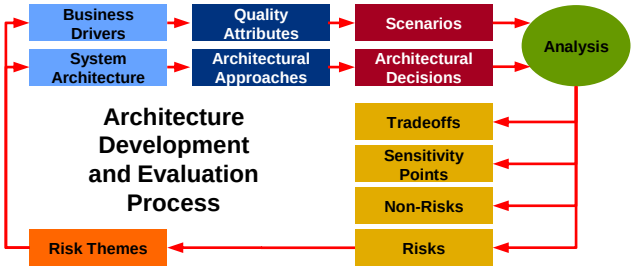
Interdisciplinary Trade Studies

- 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

Does this sound familiar?

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?

The Importance of System Engineering

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

- "costs … of major defense acquisition programs increased 26 percent and development costs increased by 40 percent from first estimates"
- "programs … failed to deliver capabilities when promised—often forcing warfighters to spend additional funds on maintaining legacy systems"
- "current programs experienced, on average, a 21-month delay in delivering initial capabilities to the warfighter"

Why?

"… 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 …

The Problem

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?

The Solution

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 Systems Engineering by relating the achievement of quantifiable and persistent improvement in program performance through appropriate application of systems engineering principles and practices

Participants

The SE Effectiveness Study

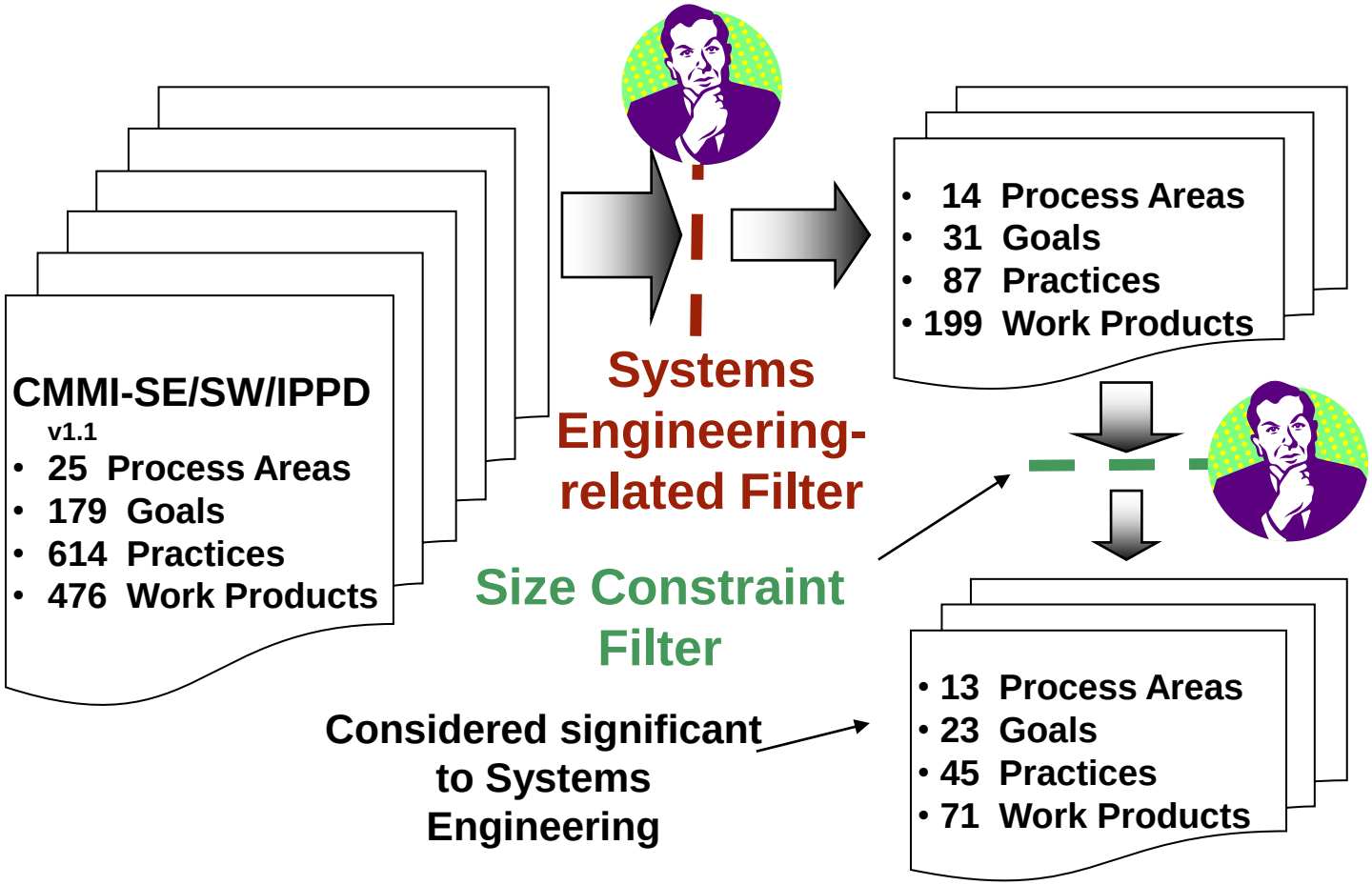
Method

- 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 assessed parameters

Survey Tenets

- All data is submitted anonymously
- All data is handled confidentially by the SEI
- Only aggregated data is released

Artifact-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

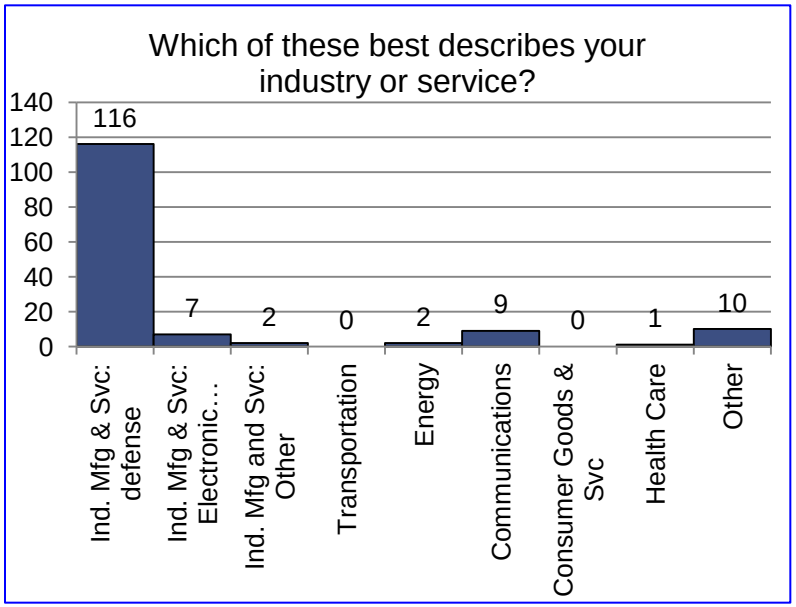
- **Program Challenge** – some programs are more complex than others
- **Prior Experience** – some acquirers are more capable than others

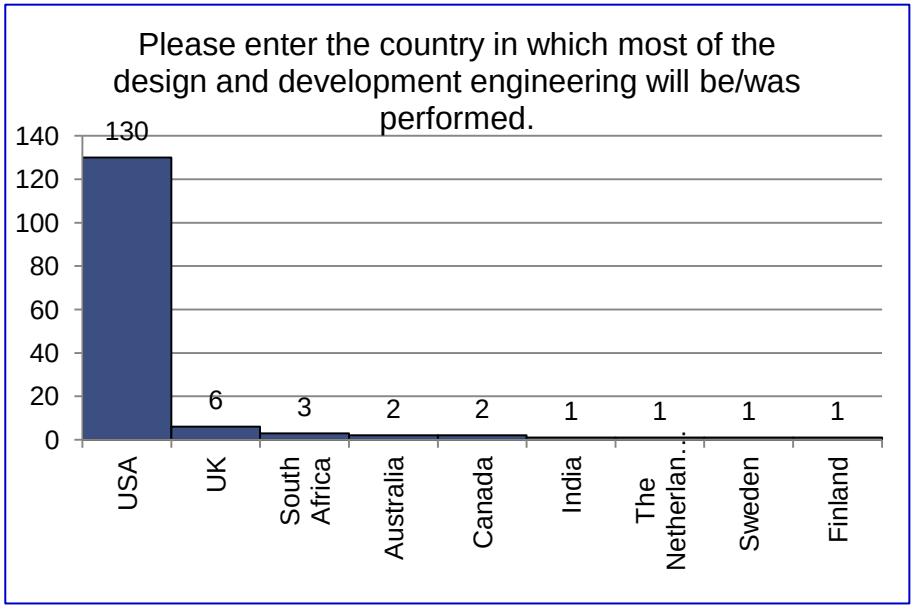
Study Participants

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

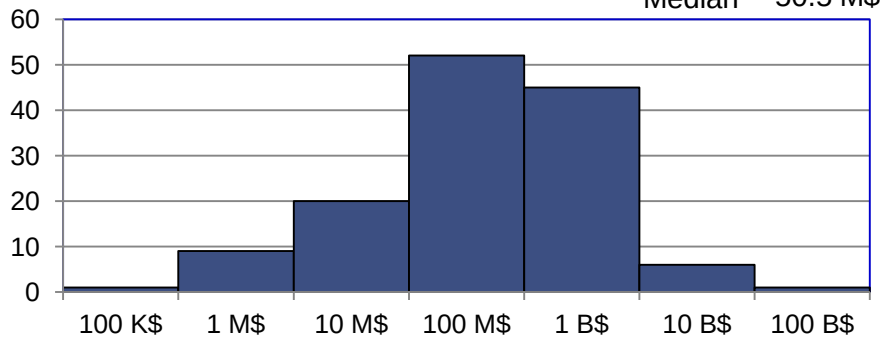




Study Results

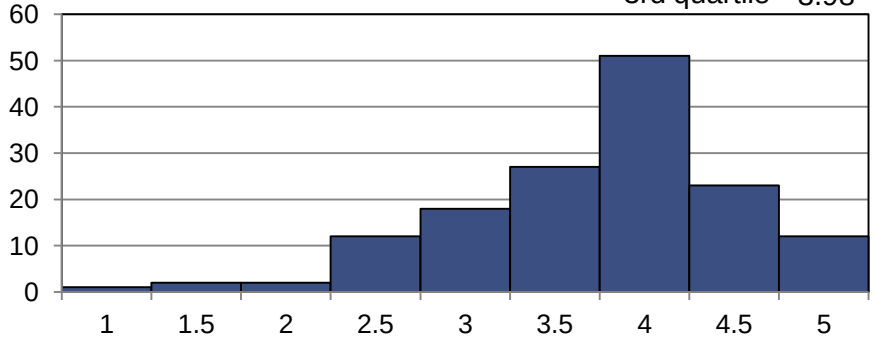
Total program contract value

Mean	488 M$
Std. Dev.	2.22 B$
Median	50.5 M$



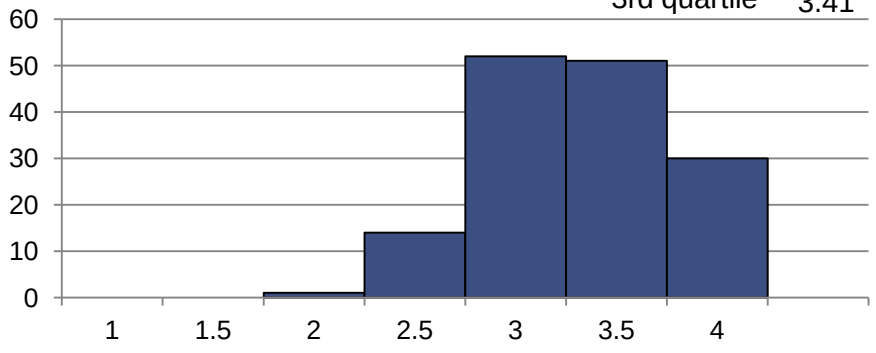
Program Performance (Perf)

1st quartile	3.03
Median (2nd quartile)	3.58
3rd quartile	3.98



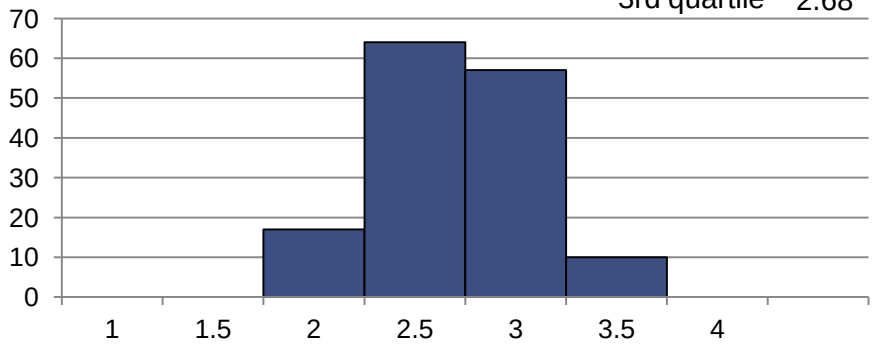
Total SE Deployed on Program (SEC_Total)

1st quartile	2.78
Median (2nd quartile)	3.03
3rd quartile	3.41



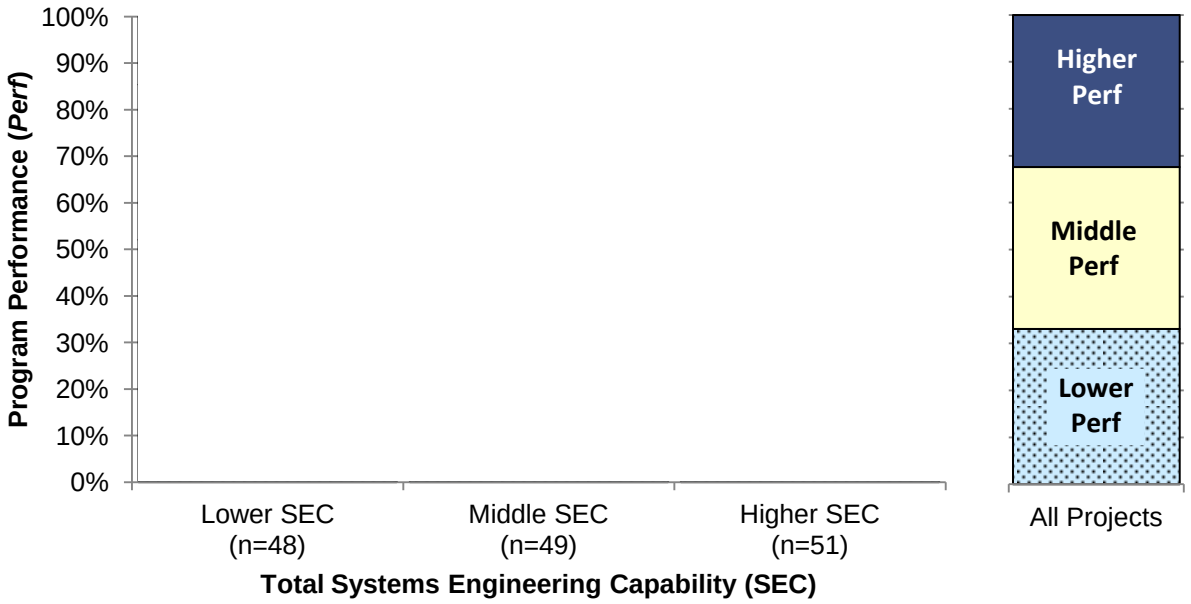
Program Challenge

1st quartile	2.22
Median (2nd quartile)	2.50
3rd quartile	2.68



The Bottom Line

Program Performance vs. Total SE



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

For Lower SEC programs, only 15% deliver higher performance

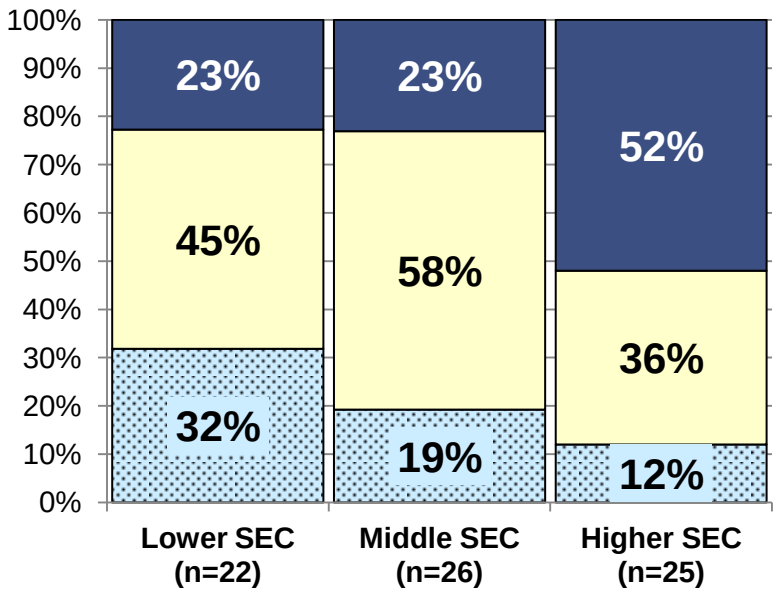
For Middle SEC programs, 24% deliver higher performance

For Higher SEC programs, 57% deliver higher performance

Gamma = 0.49 represents a VERY STRONG relationship

The Effect of Program Challenge

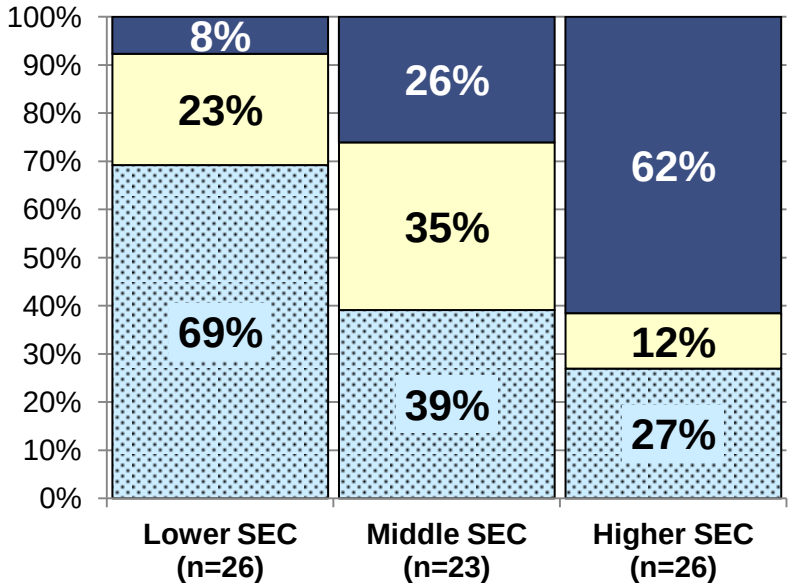
Perf vs. SEC_Total (Low PC)



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)



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

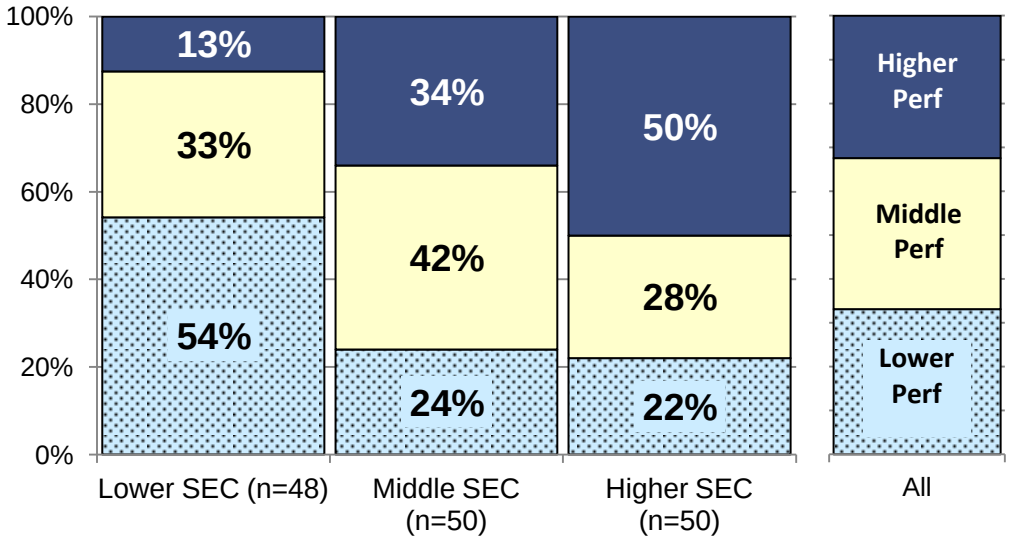
Our survey questions addressed 11 areas of SE Activities

- 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

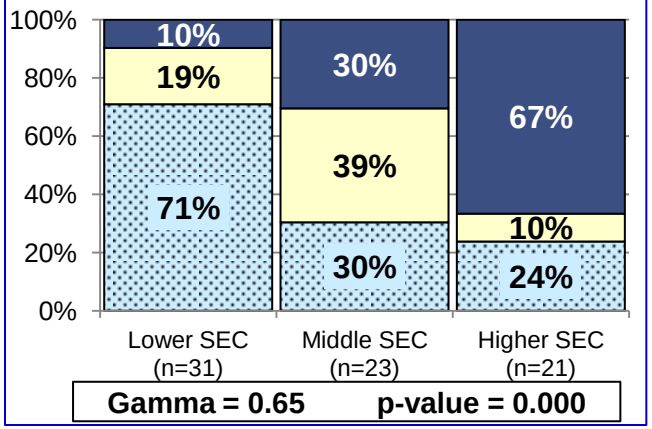
Program Planning vs. Performance

Perf vs. SEC-PP



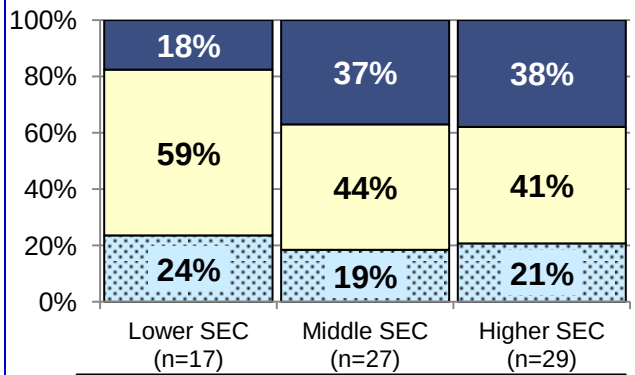
Gamma = 0.46 **p-value = 0.000**

Perf vs. SEC-PP (High PC)



Gamma = 0.65 **p-value = 0.000**

Perf vs. SEC-PP (Low PC)



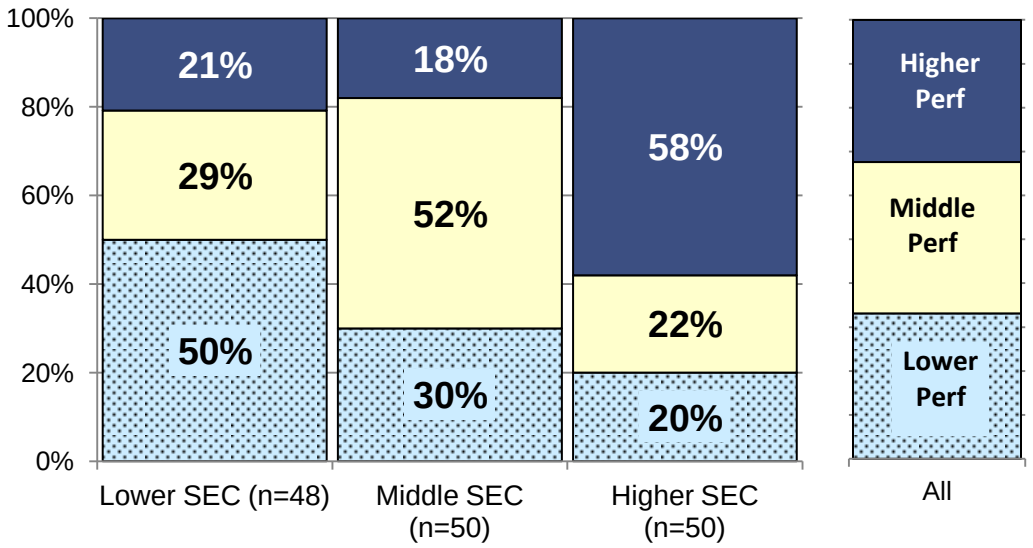
Gamma = 0.16 **p-value = 0.313**

The relationship:

for the set of all programs	**0.46 = Very Strong**
for the set of High Challenge programs	**0.65 = Very Strong**
for the set of Low Challenge programs	**0.16 = Weak**

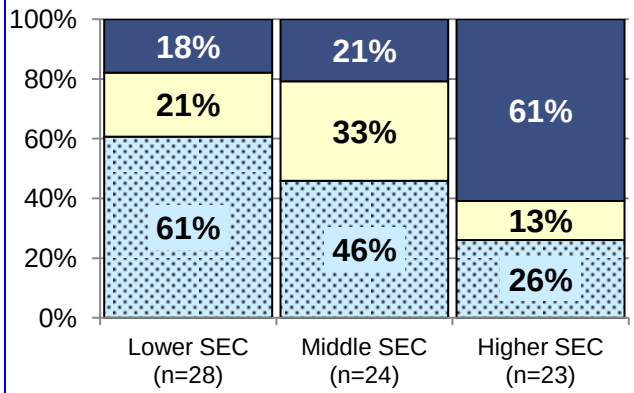
Requirements Dev't & Mg't vs. Performance

Perf vs. SEC-REQ



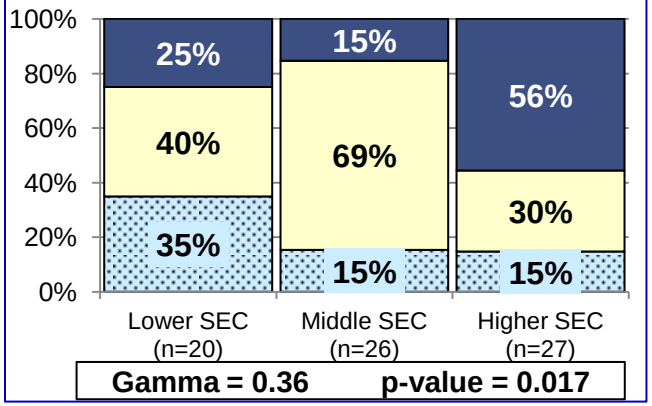
Gamma = 0.44 p-value = 0.000

Perf vs. SEC-REQ (High PC)



Gamma = 0.5 p-value = 0.001

Perf vs. SEC-REQ (Low PC)



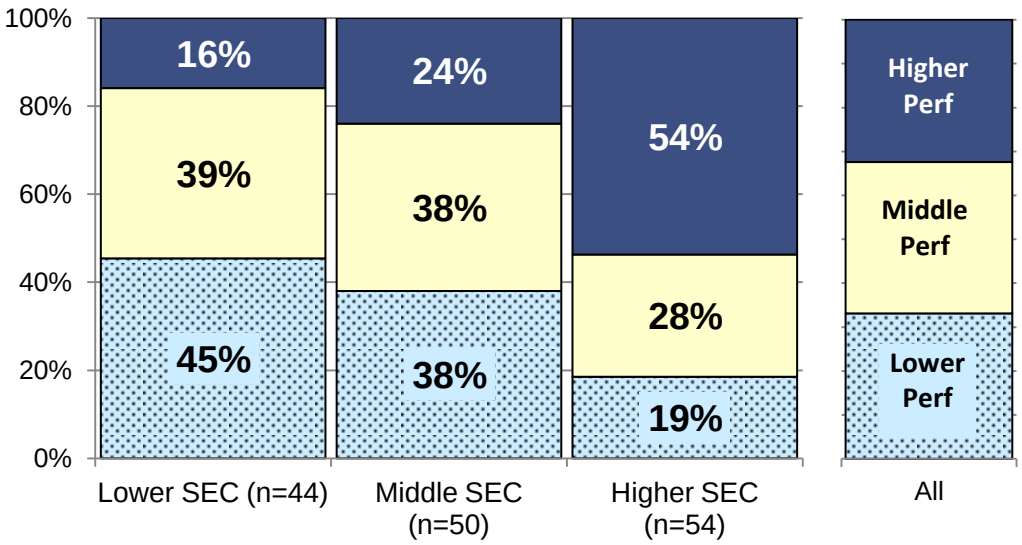
Gamma = 0.36 p-value = 0.017

The relationship:

for the set of all programs	**0.44 = Very Strong**
for the set of High Challenge programs	**0.50 = Very Strong**
for the set of Low Challenge programs	**0.36 = Strong**

Verification vs. Performance

Perf vs. SEC-VER

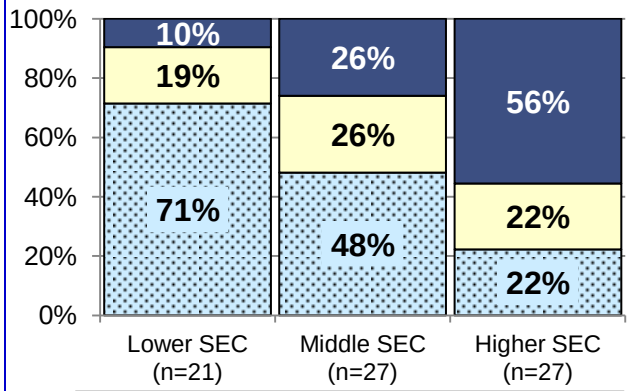


Gamma = 0.43 p-value = 0.000

The relationship:

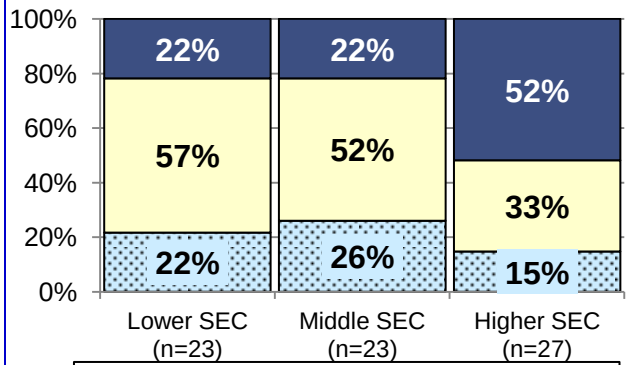
for the set of all programs	**0.43 = Very Strong**
for the set of High Challenge programs	**0.60 = Very Strong**
for the set of Low Challenge programs	**0.27 = Moderate**

Perf vs. SEC-VER (High PC)



Gamma = 0.6 p-value = 0.000

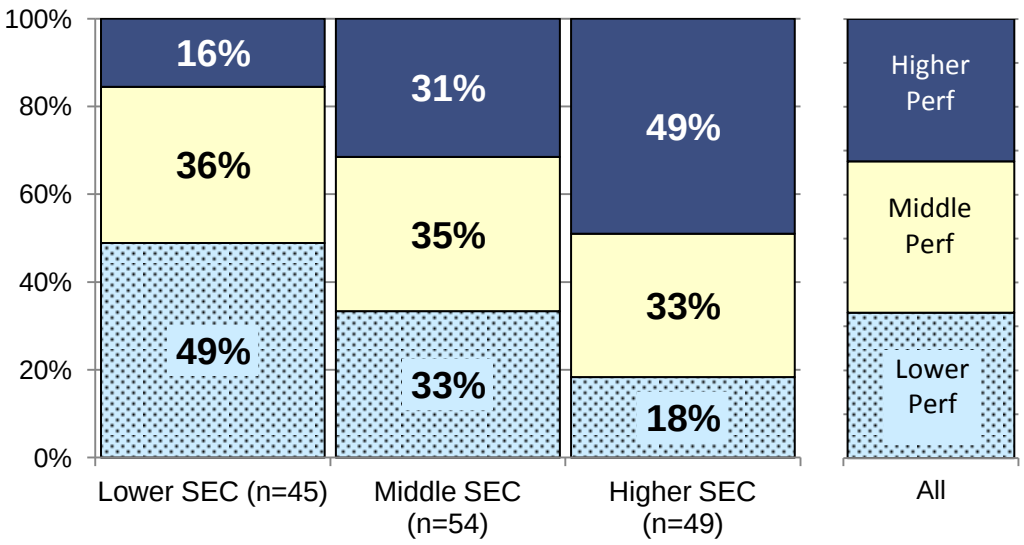
Perf vs. SEC-VER (Low PC)



Gamma = 0.27 p-value = 0.084

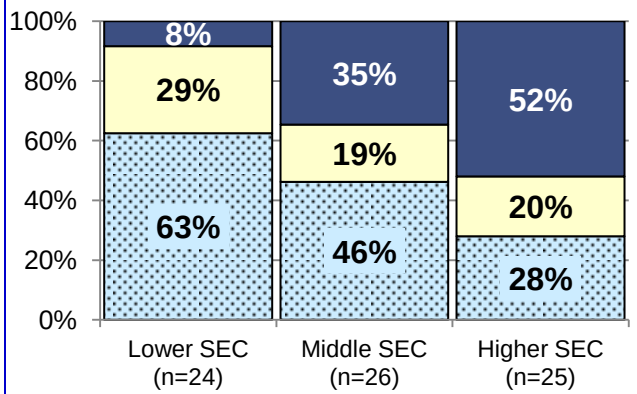
Architecture vs. Performance

Perf vs. SEC-ARCH



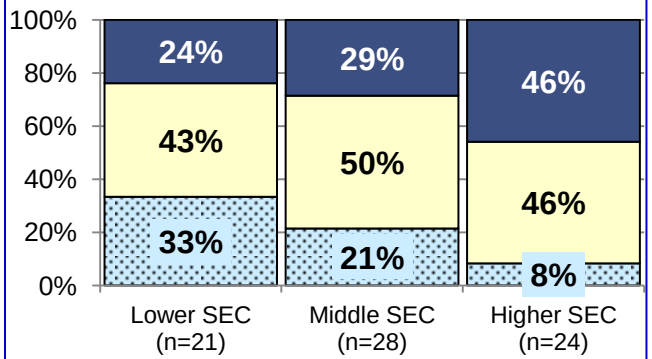
Gamma = 0.41 p-value = 0.000

Perf vs. SEC-ARCH (High PC)



Gamma = 0.49 p-value = 0.001

Perf vs. SEC-ARCH (Low PC)

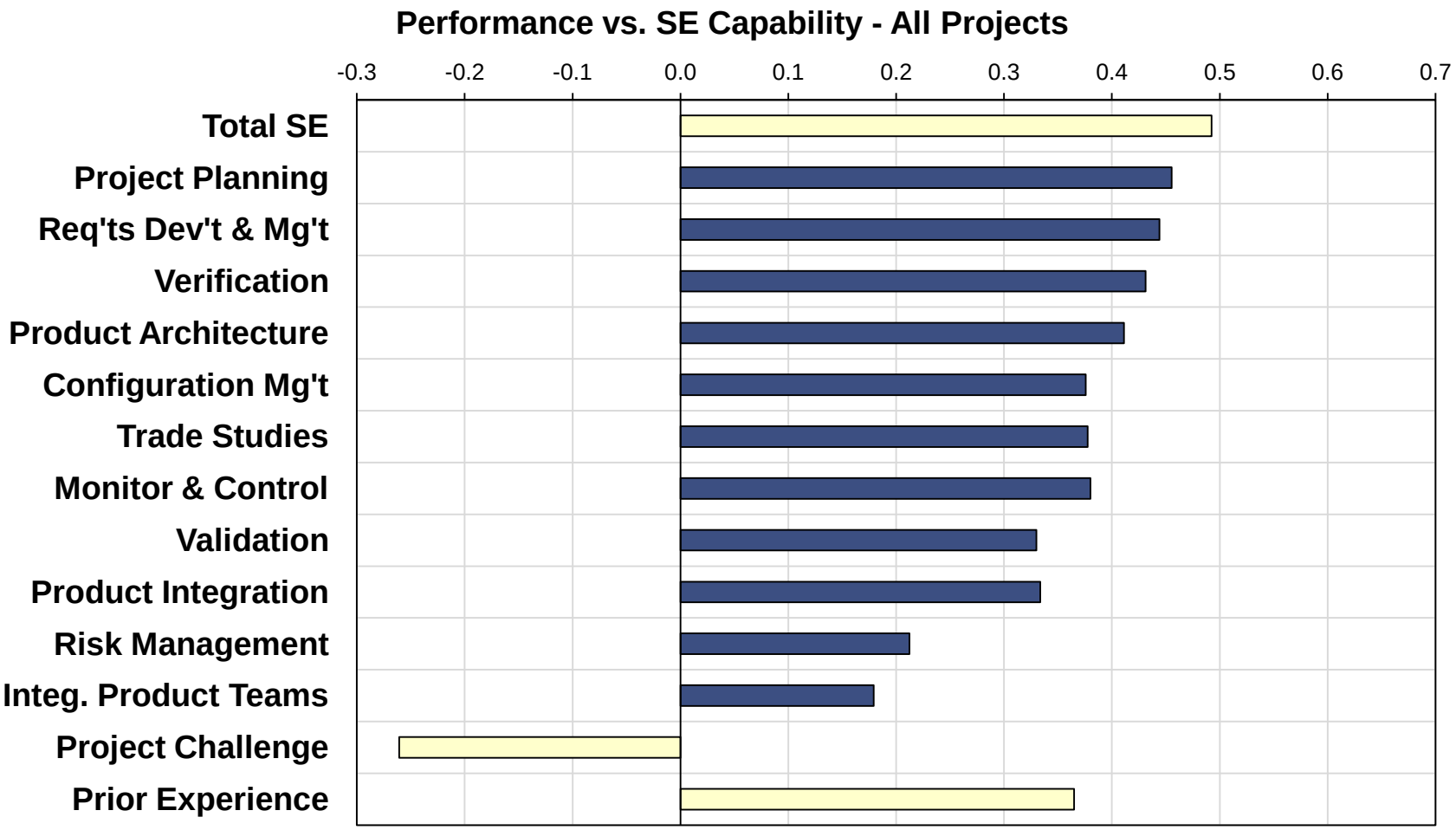


Gamma = 0.31 p-value = 0.051

The relationship:

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

Summary of Relationships

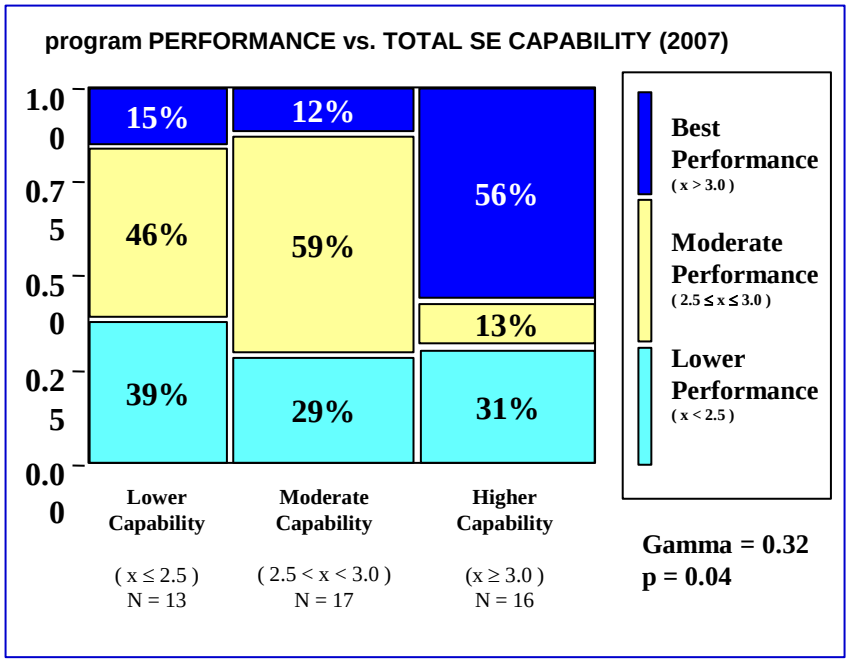


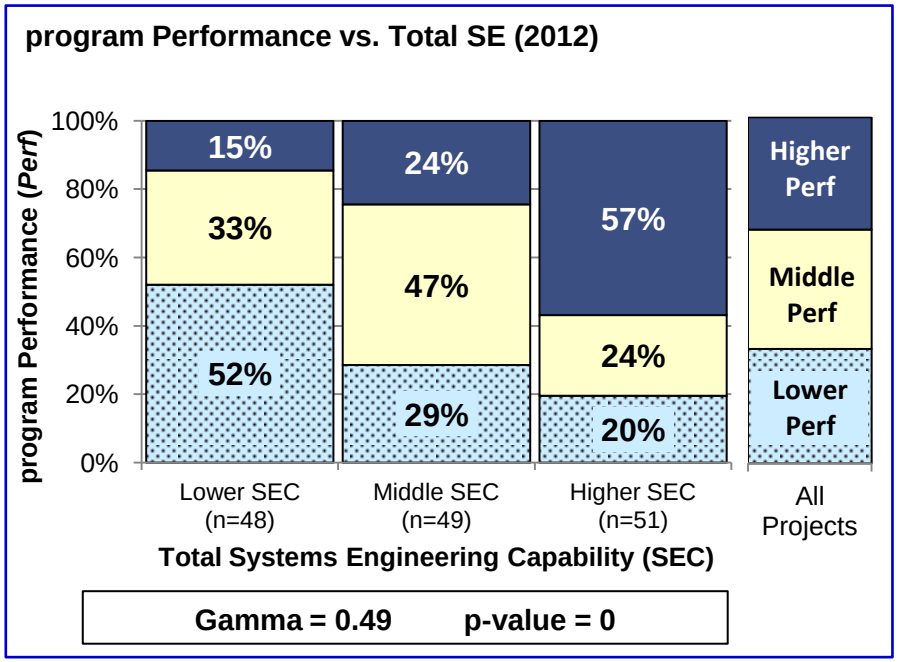
Comparison with 2007 SE Effectiveness Study [1]

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

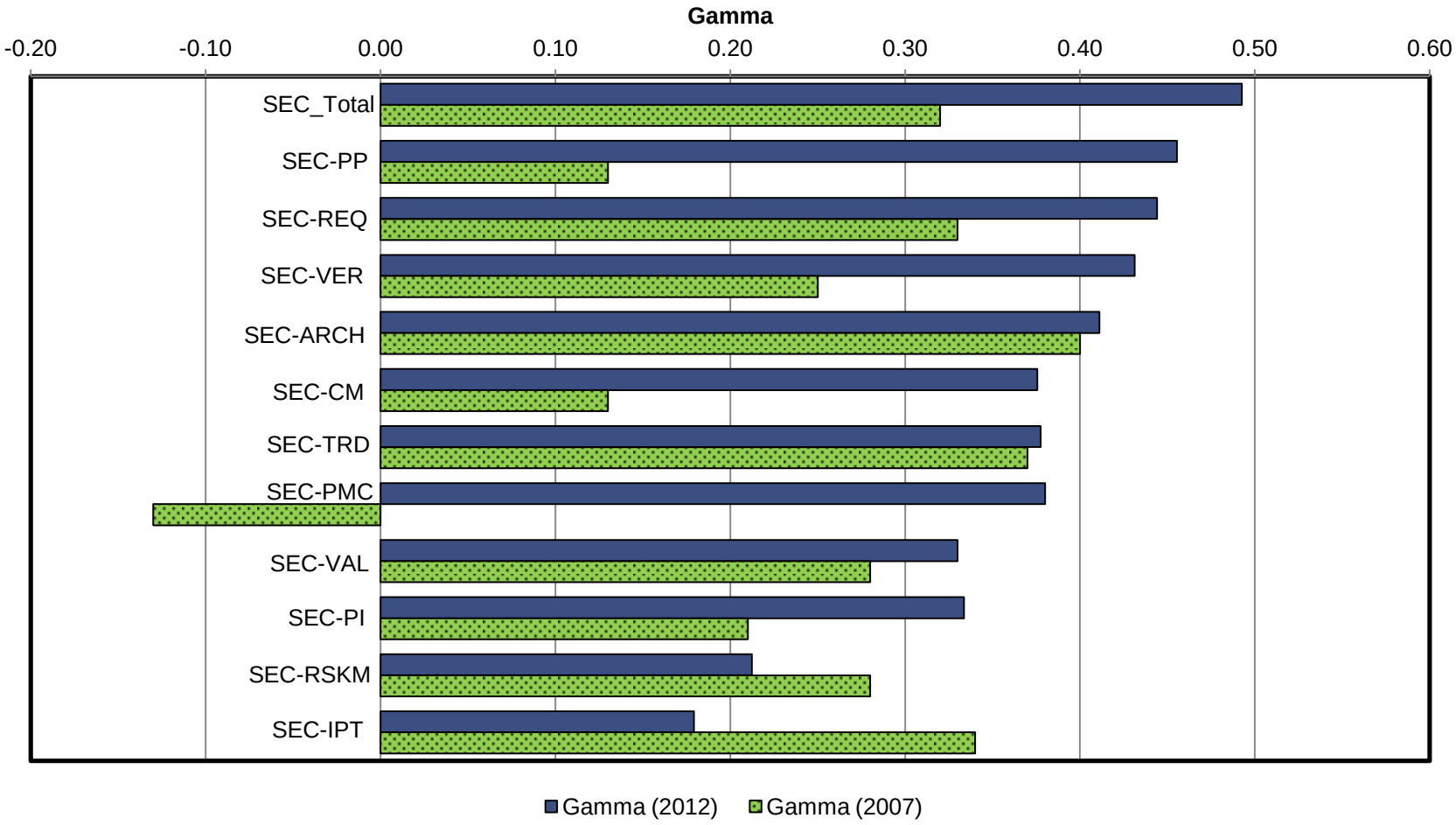
- Probably due to reduction in noise resulting from the larger sample size

Most results from the two studies are generally in agreement





Comparison with 2007 SE Effectiveness Study 2



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.

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

The Plan

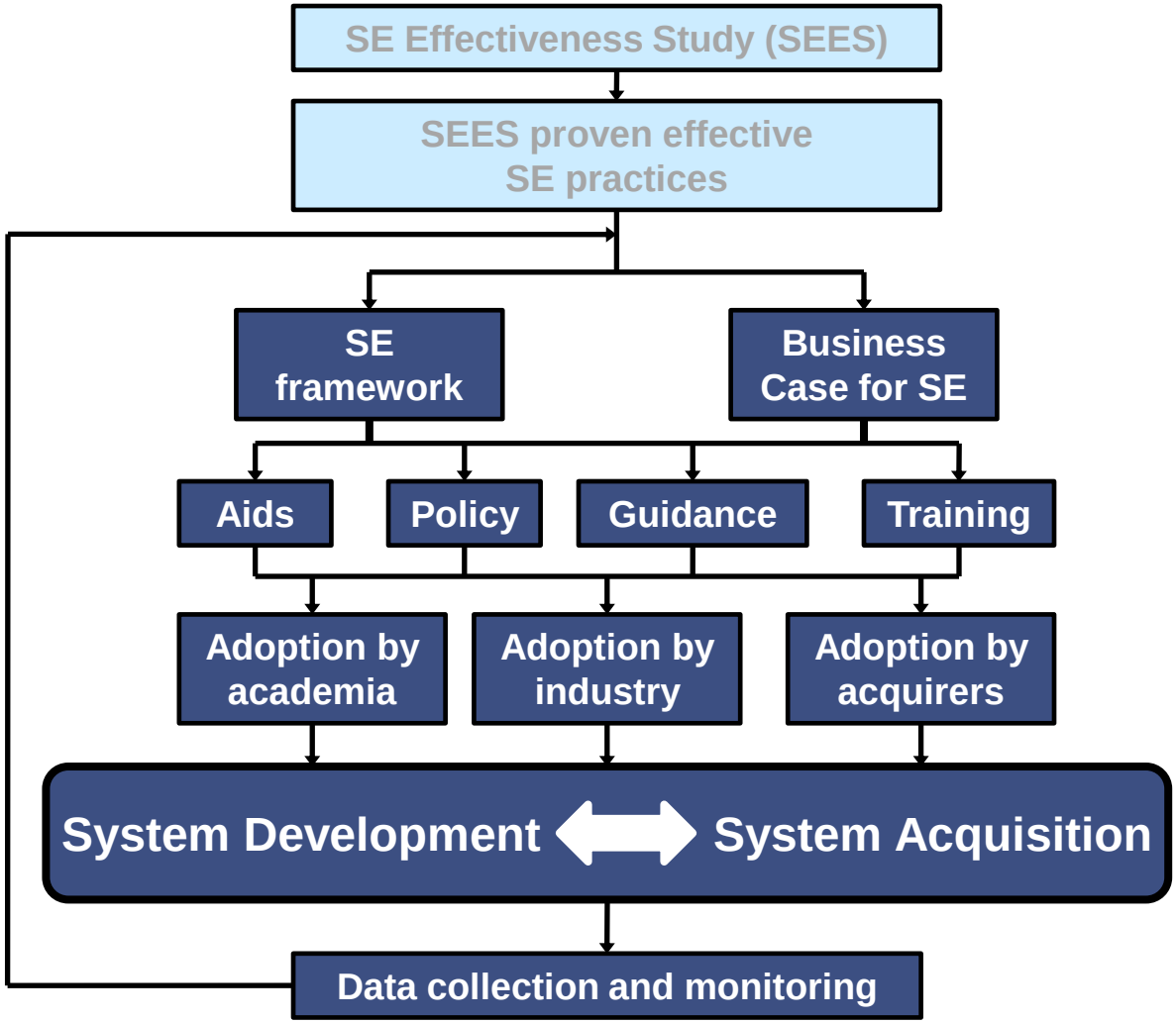
Phase I

Phase II

Mar-2012 thru Jun 2013

Phase III

Jun-2013 thru Oct 2013



Call to Action

Download the 2012 report at *http://www.sei.cmu.edu/library/abstracts/reports/12sr009.cfm*

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

Help with the continuing effort of showing the value of SE

- Join the INCOSE SE Effectiveness Working Group
  - Go to *http://www.incose.org/practice/techactivities/wg/seewg/*
  - Or contact Joseph Elm (*joseph.elm@incose.org*)
- Join the NDIA SE Effectiveness Committee
  - Go to *http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Pages/Systems_Engineering_Effectiveness_Committee.aspx*
  - Or contact Al Brown (*alan.r.brown2@boeing.com*)

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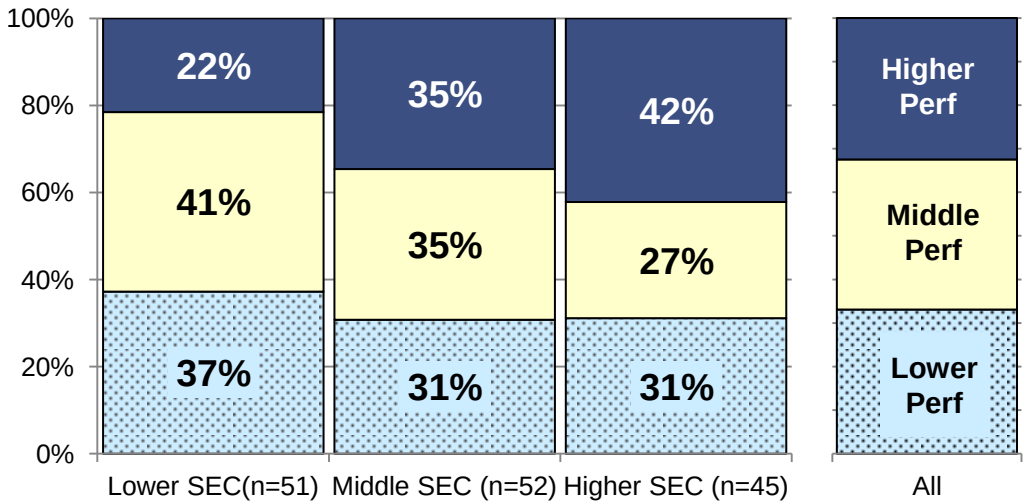
BACK UP

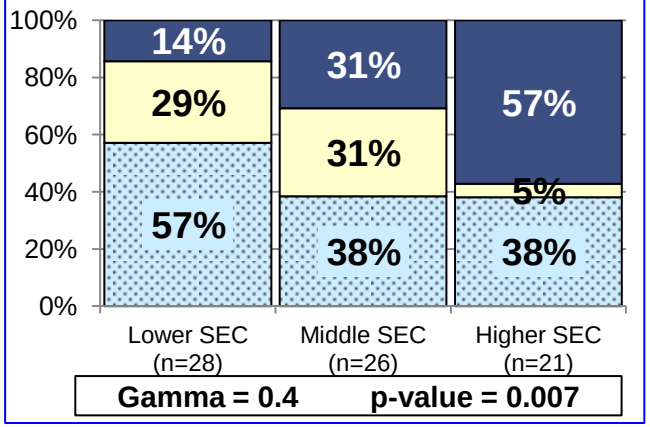
Integrated Product Teams vs. Performance

Perf vs. SEC-IPT



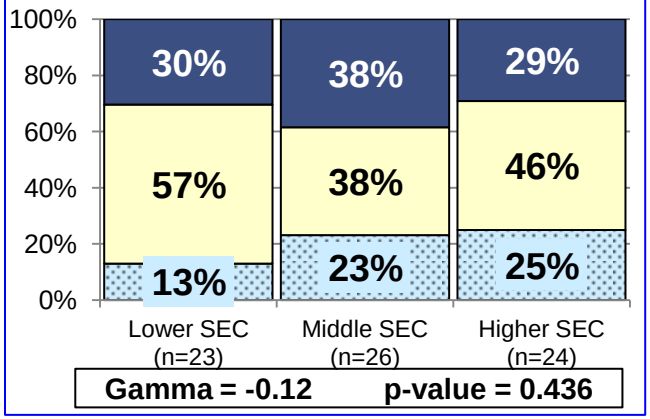
Gamma = 0.18 p-value = 0.101

Perf vs. SEC-IPT (High PC)



Gamma = 0.4 p-value = 0.007

Perf vs. SEC-IPT (Low PC)



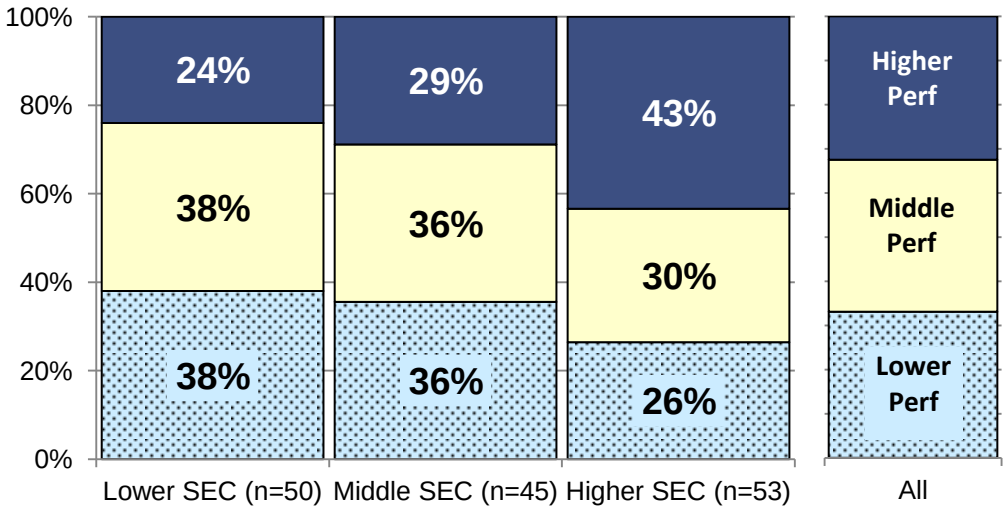
Gamma = -0.12 p-value = 0.436

The relationship:

for the set of all programs	**0.18 = Weak**
for the set of High Challenge programs	**0.40 = Strong**
for the set of Low Challenge programs	**-0.12 = Weak Neg.**

Risk Management vs. Performance

Perf vs. SEC-RSKM

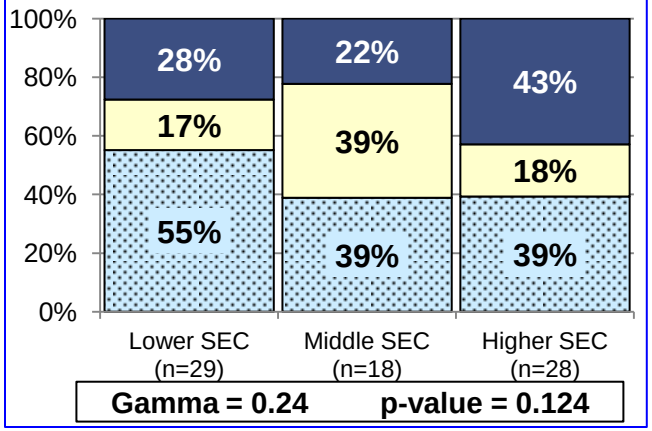


Gamma = 0.21 p-value = 0.05

The relationship:

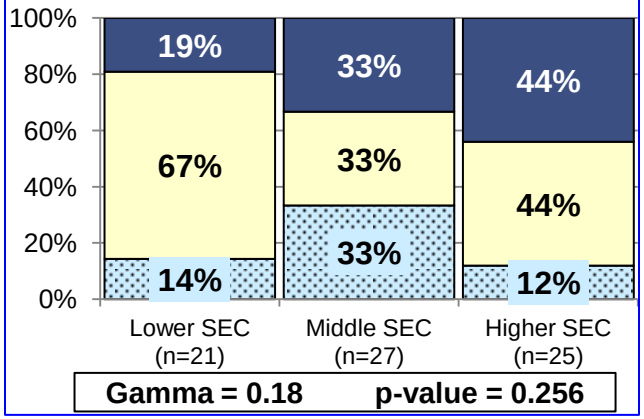
for the set of all programs	**0.21 = Moderate**
for the set of High Challenge programs	**0.24 = Moderate**
for the set of Low Challenge programs	**0.18 = Weak**

Perf vs. SEC-RSKM (High PC)



Gamma = 0.24 p-value = 0.124

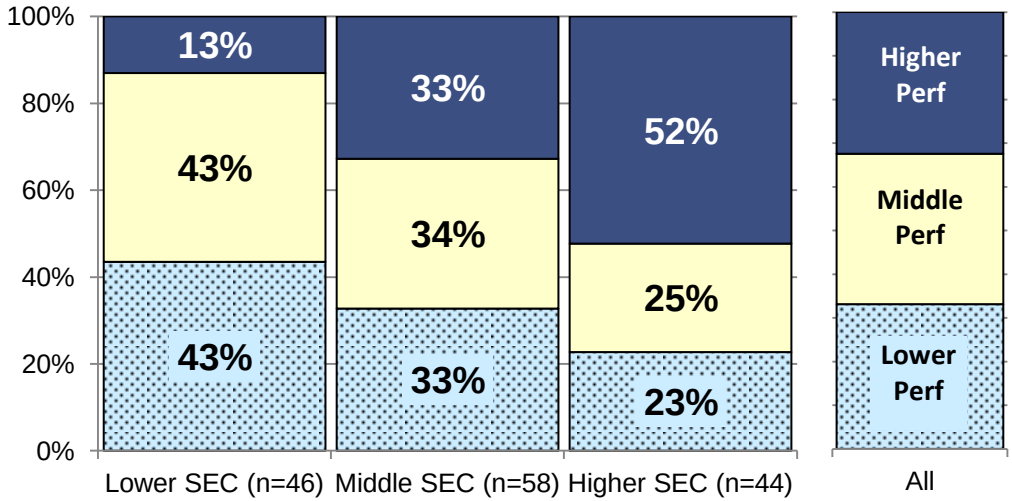
Perf vs. SEC-RSKM (Low PC)



Gamma = 0.18 p-value = 0.256

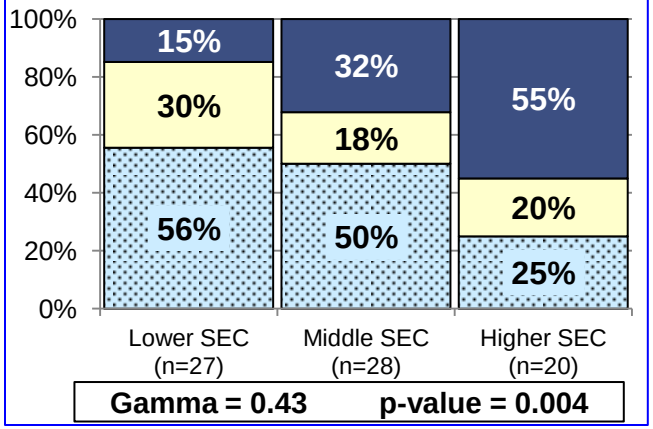
Trade Studies vs. Performance

Perf vs. SEC-TRD



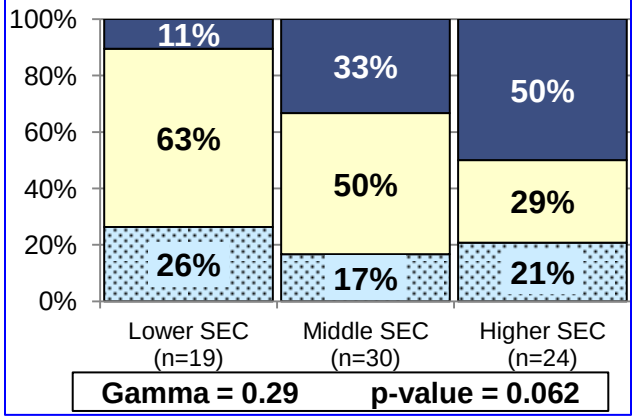
Gamma = 0.38 p-value = 0

Perf vs. SEC-TRD (High PC)



Gamma = 0.43 p-value = 0.004

Perf vs. SEC-TRD (Low PC)



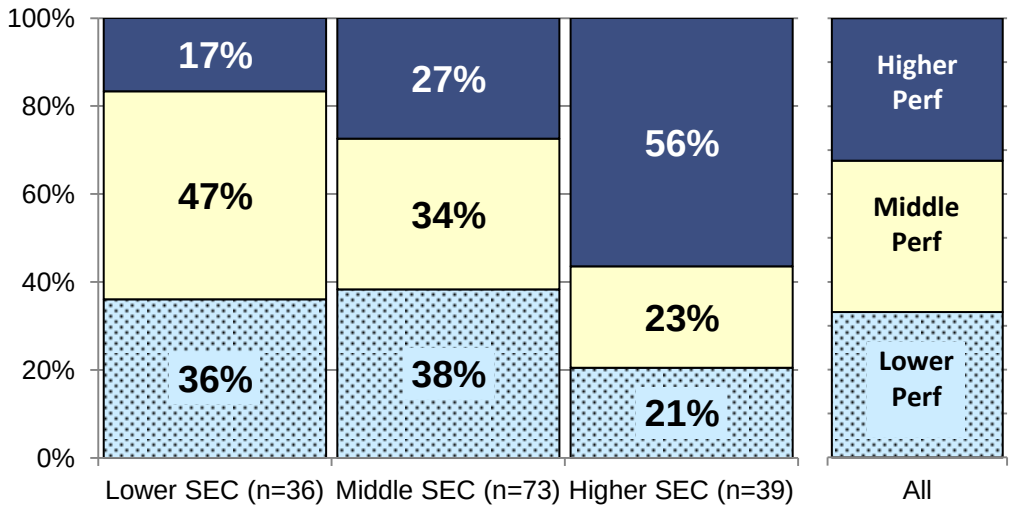
Gamma = 0.29 p-value = 0.062

The relationship:

for the set of all programs	**0.38 = Strong**
for the set of High Challenge programs	**0.43 = Very Strong**
for the set of Low Challenge programs	**0.29 = Moderate**

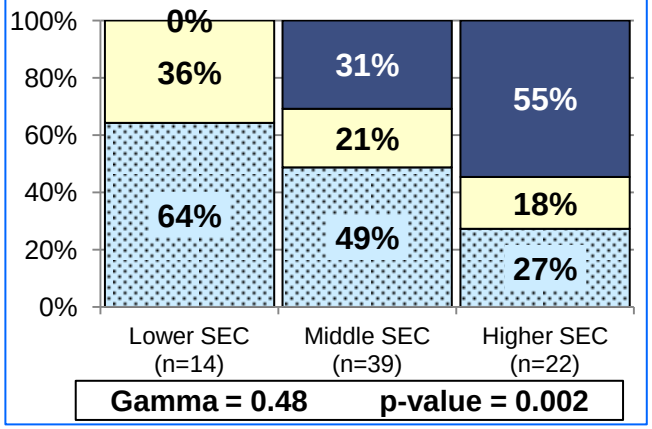
Validation vs. Performance

Perf vs. SEC-VAL



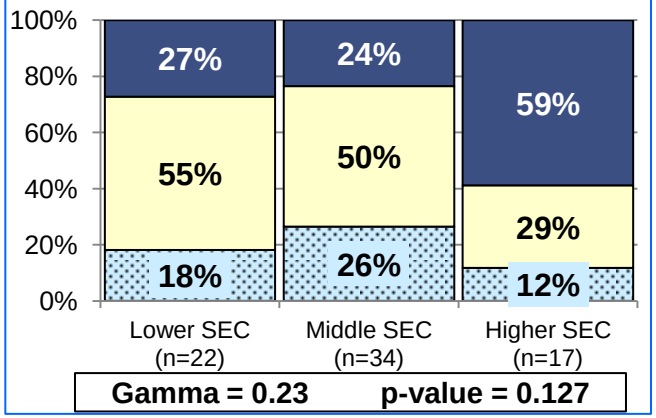
Gamma = 0.33 p-value = 0.003

Perf vs. SEC-VAL (High PC)



Gamma = 0.48 p-value = 0.002

Perf vs. SEC-VAL (Low PC)



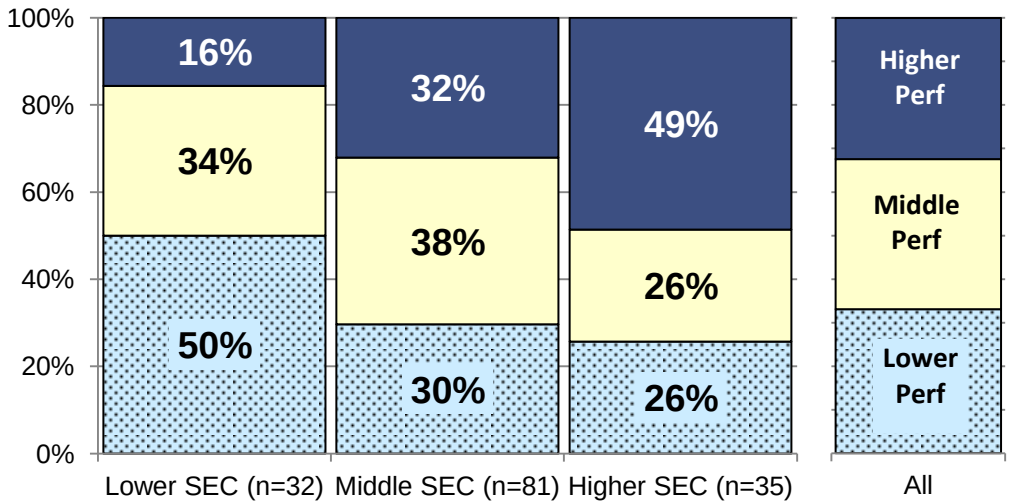
Gamma = 0.23 p-value = 0.127

The relationship:

for the set of all programs	**0.33 = Strong**
for the set of High Challenge programs	**0.48 = Very Strong**
for the set of Low Challenge programs	**0.23 = Moderate**

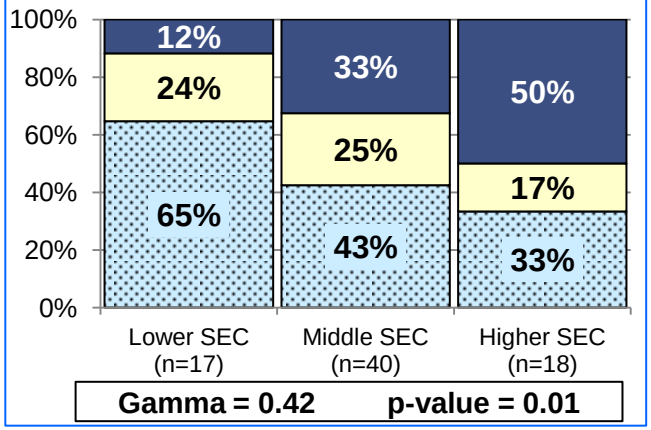
Product Integration vs. Performance

Perf vs. SEC-PI



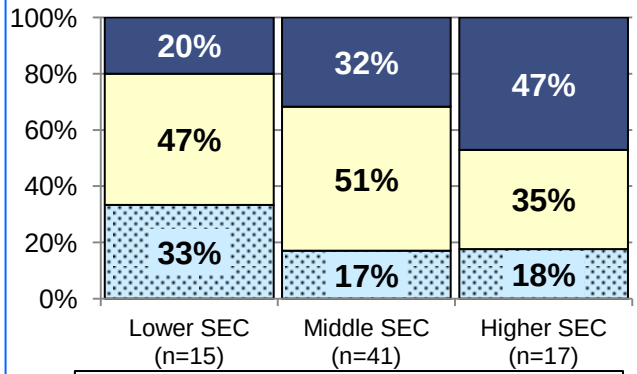
Gamma = 0.33 p-value = 0.003

Perf vs. SEC-PI (High PC)



Gamma = 0.42 p-value = 0.01

Perf vs. SEC-PI (Low PC)



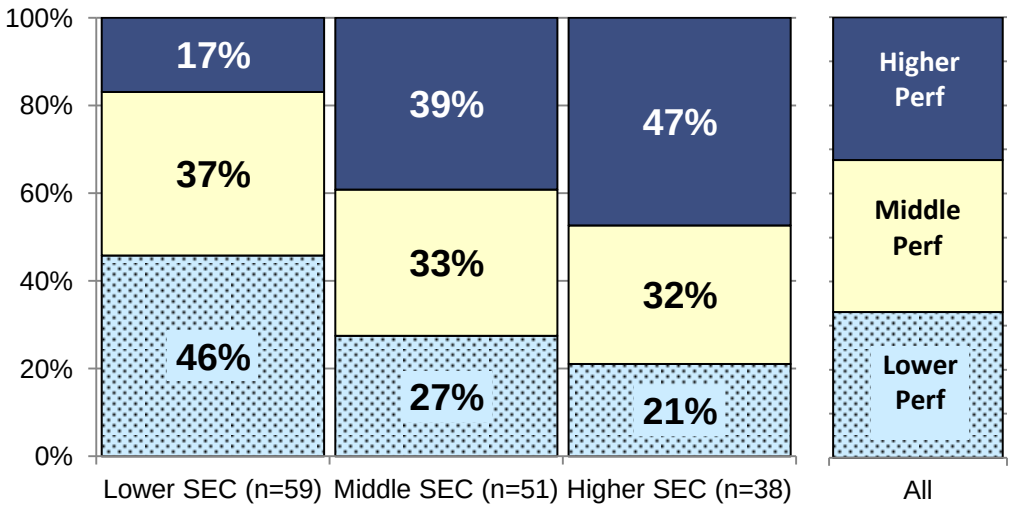
Gamma = 0.23 p-value = 0.153

The relationship:

for the set of all programs	**0.33 = Strong**
for the set of High Challenge programs	**0.42 = Very Strong**
for the set of Low Challenge programs	**0.23 = Moderate**

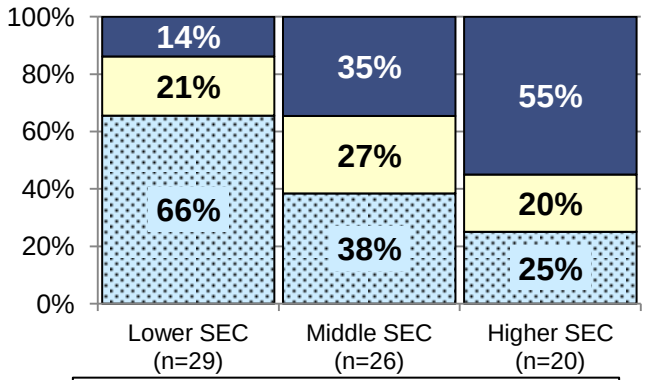
Configuration Management vs. Performance

Perf vs. SEC-CM



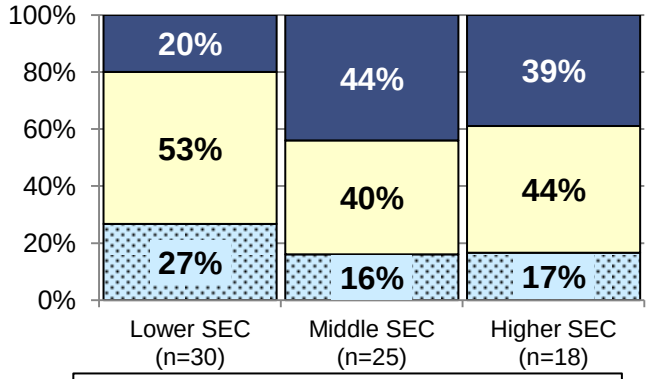
Gamma = 0.38 p-value = 0.001

Perf vs. SEC-CM (High PC)



Gamma = 0.53 p-value = 0

Perf vs. SEC-CM (Low PC)



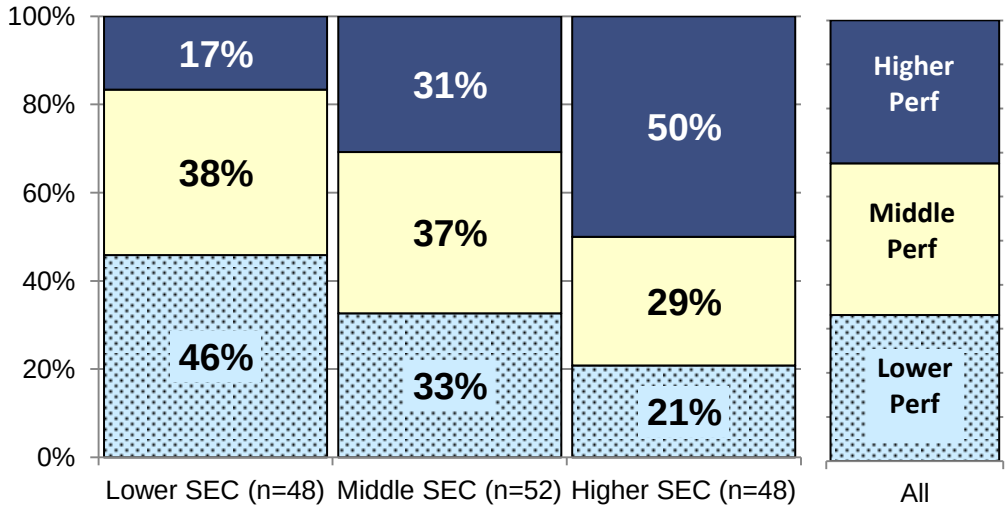
Gamma = 0.22 p-value = 0.203

The relationship:

for the set of all programs	**0.38 = Strong**
for the set of High Challenge programs	**0.53 = Very Strong**
for the set of Low Challenge programs	**0.22 = Moderate**

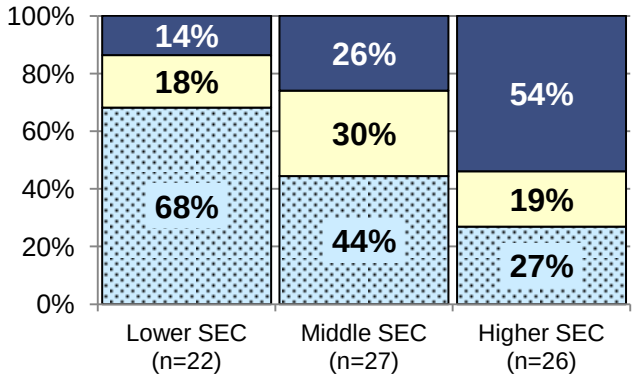
Program Monitoring & Control vs. Performance

Perf vs. SEC-PMC



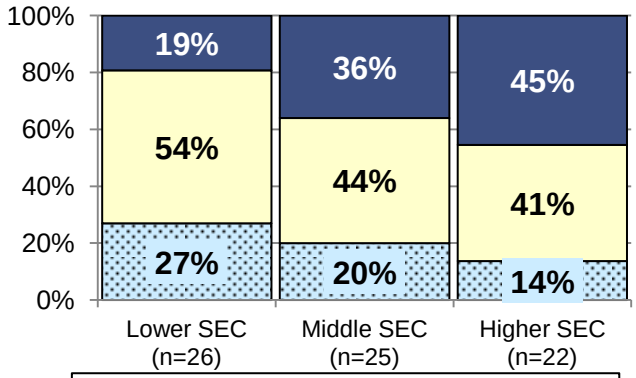
Gamma = 0.38 p-value = 0

Perf vs. SEC-PMC (High PC)



Gamma = 0.53 p-value = 0

Perf vs. SEC-PMC (Low PC)



Gamma = 0.27 p-value = 0.092

The relationship:

for the set of all programs	**0.38 = Strong**
for the set of High Challenge programs	**0.53 = Very Strong**
for the set of Low Challenge programs	**0.27 = Moderate**