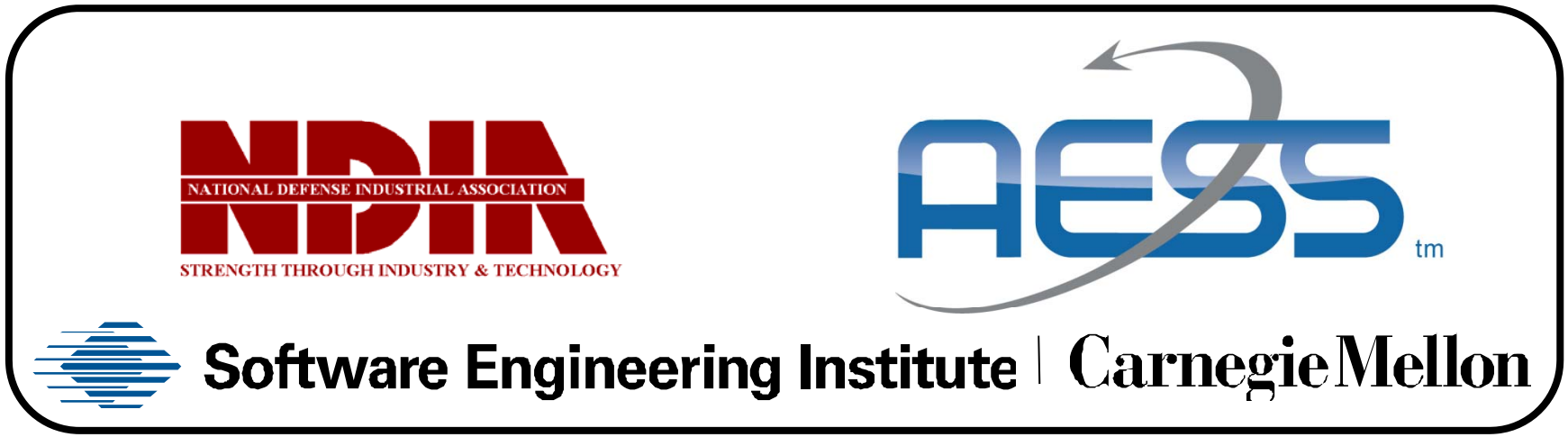


Quantifying the Effectiveness of Systems Engineering

Presenters: **Joseph P. Elm**
Dr. Dennis Goldenson

Software Engineering Institute

This material is based upon work funded and supported by the Department of Defense under Contract No. FA8721-05-C-0003 with Carnegie Mellon University for the operation of the Software Engineering Institute, a federally funded research and development center.

DM-0000243

The Value of System Engineering

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

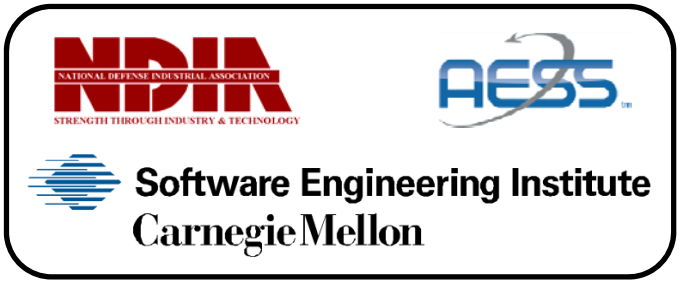
- "costs … of major defense acquisition programs increased 26 percent and development costs increased by 40 percent from first estimates"
- "programs … failed to deliver capabilities when promised—often forcing warfighters to spend additional funds on maintaining legacy systems"
- "current programs experienced, 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 …

Showing the Value of SE:
The 2012 SE Effectiveness Study

Performed by NDIA, IEEE-AESS, and SEI



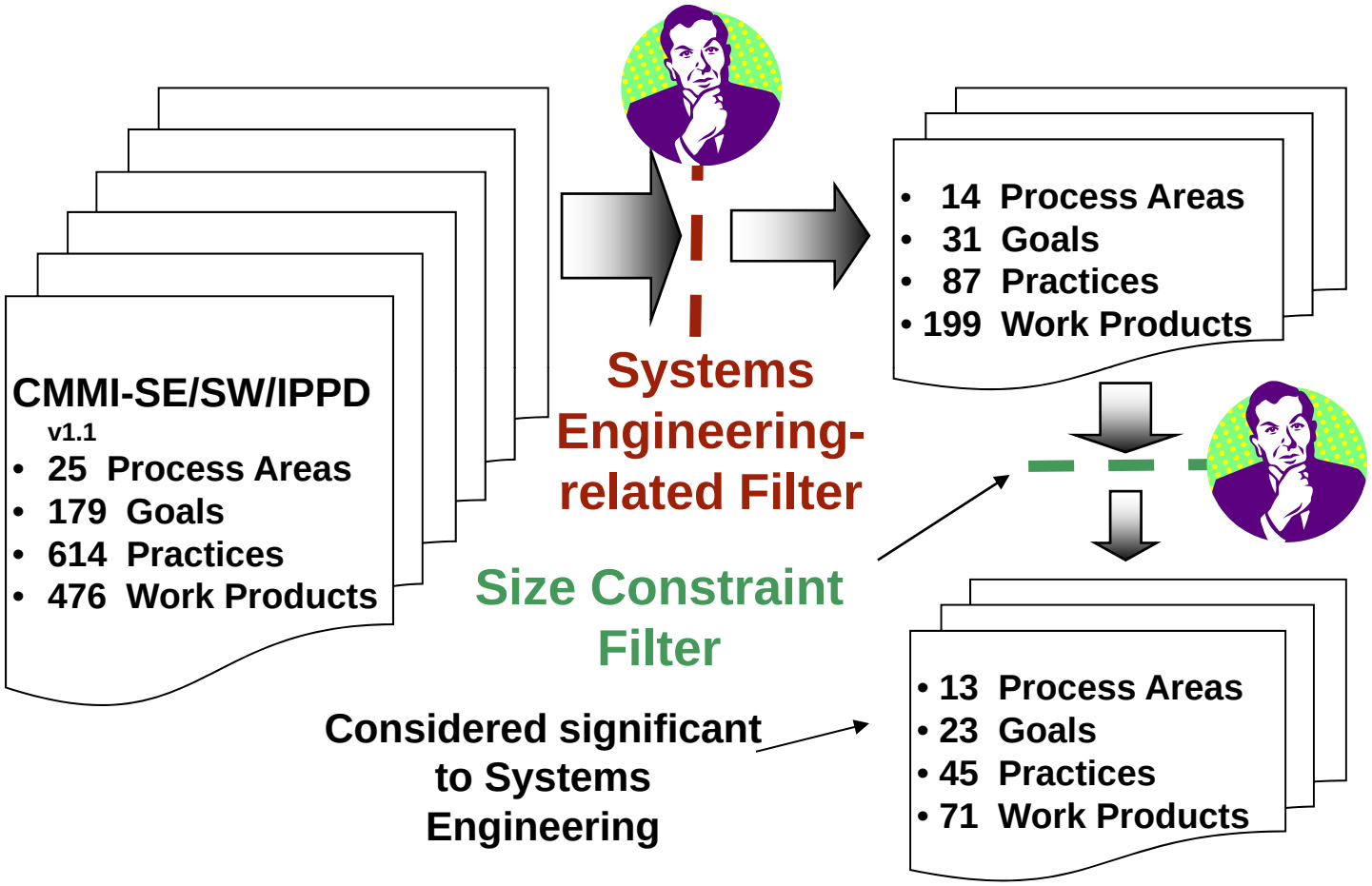
Method

- Contact development programs using the resources of NDIA, AESS, and INCOSE
- Survey programs to assess their:
  - SE activities
  - Program performance (cost, schedule, technical)
  - Degree of challenge
- Analyze responses for statistical relationships between assessed data

Survey Tenets

- All data submitted anonymously
  - necessary to collect proprietary data and promote truthful responses
- All data handled confidentially by the SEI
- Only aggregated data is released (no ID of person, program, or organization)

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

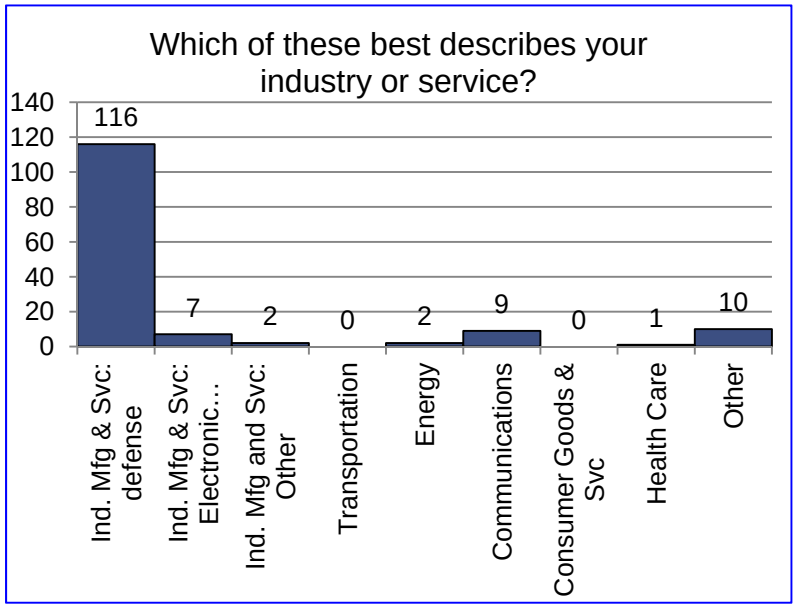
- **Program Challenge** – some programs are more complex than others
- **Prior Experience** – some acquirers are more capable than others

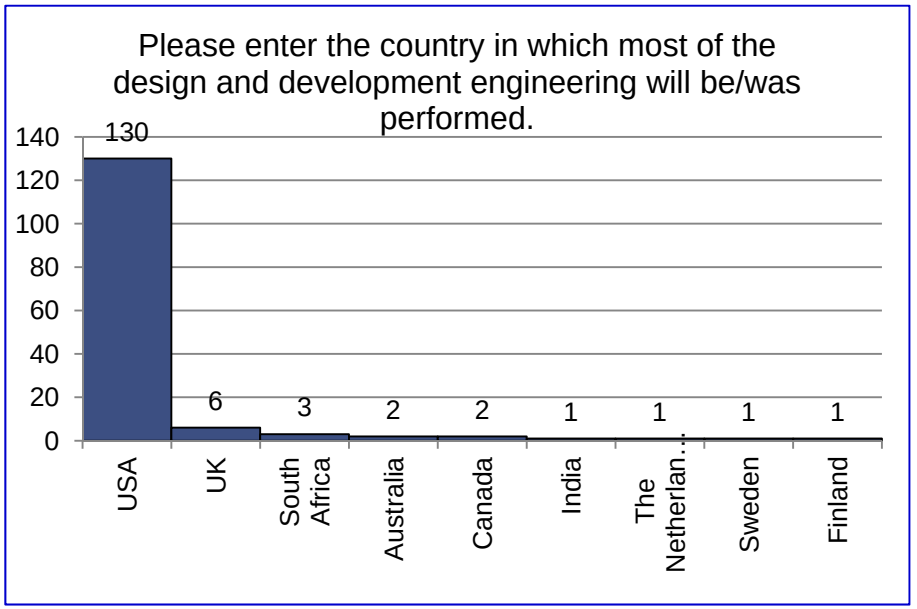
Study Participants

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

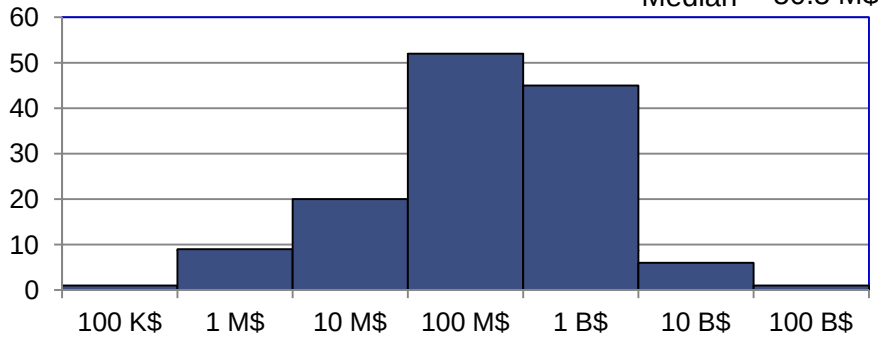




Study Results

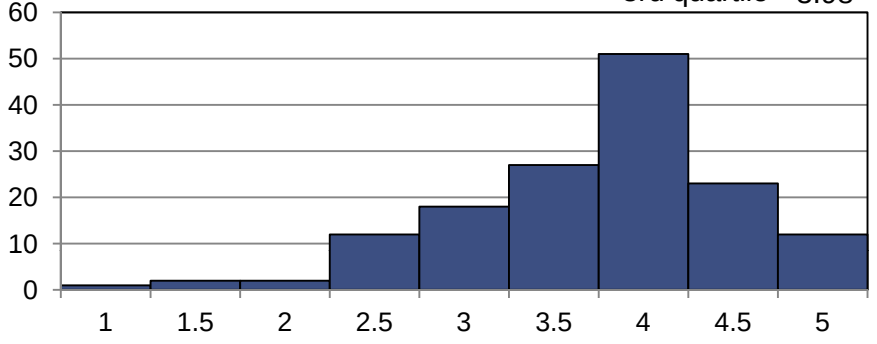
Total program contract value

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



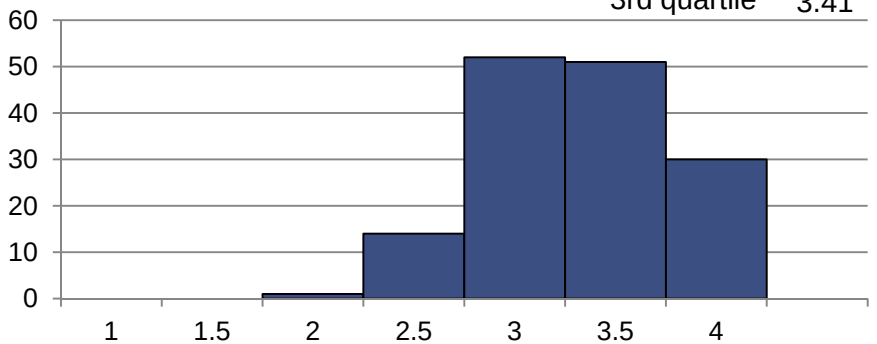
Program Performance (Perf)

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



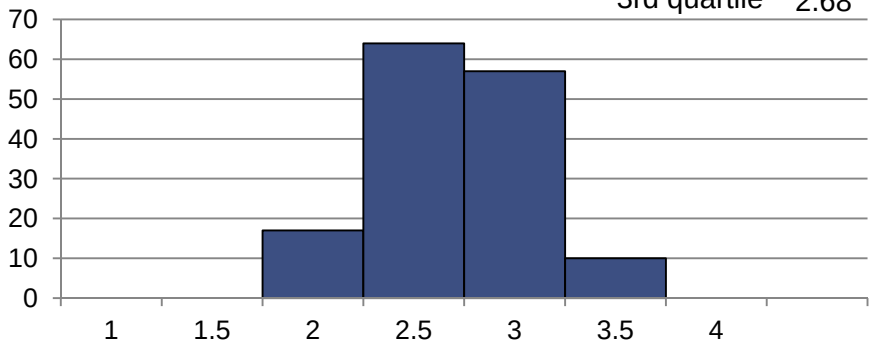
Total SE Deployed on Program (SEC_Total)

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

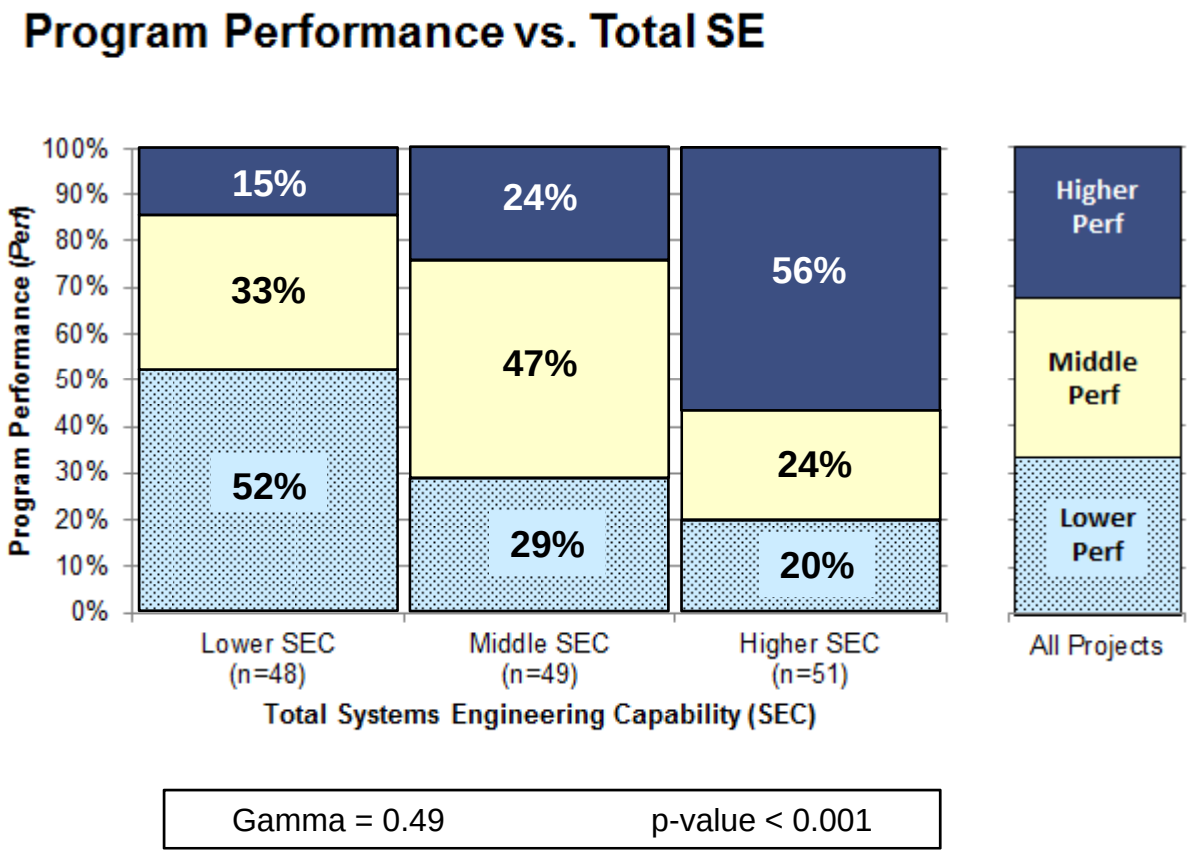


Program Challenge

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



The Bottom Line



Gamma = 0.49	p-value < 0.001

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

For Lower SEC programs, only 15% deliver higher performance

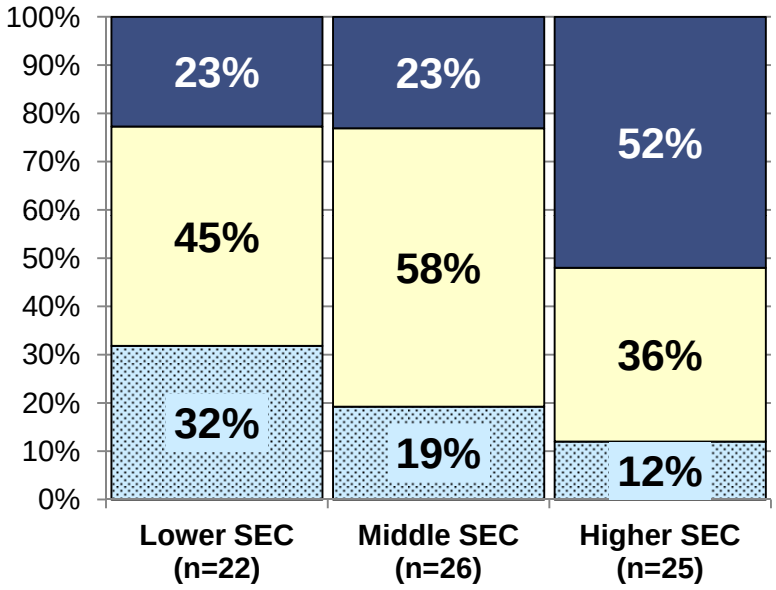
For Middle SEC programs, 24% deliver higher performance

For Higher SEC programs, 57% deliver higher performance

Gamma = 0.49 represents a VERY STRONG relationship

The Effect of Program Challenge

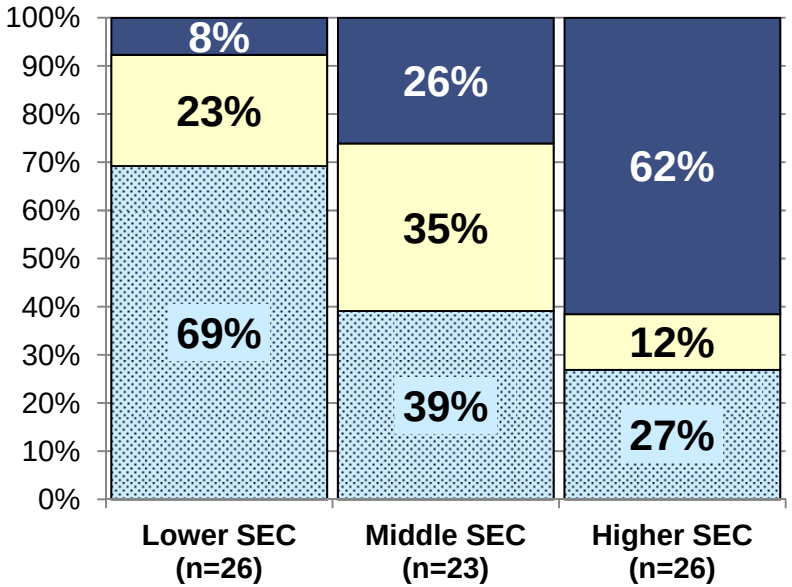
Perf vs. SEC_Total (Low PC)



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

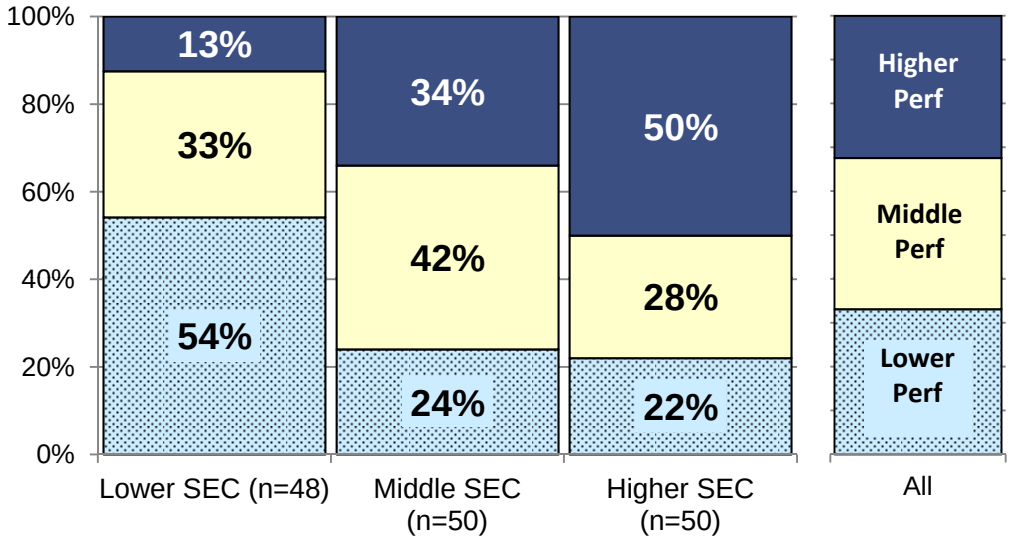
Our survey questions addressed 11 areas of SE Activities

- 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

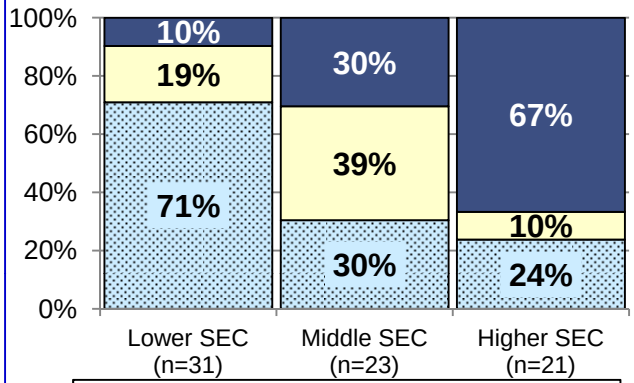
Program Planning vs. Performance

Perf vs. SEC-PP



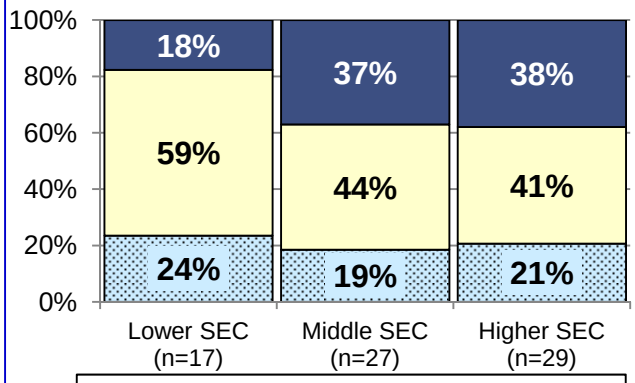
Gamma = 0.46 p-value = 0.000

Perf vs. SEC-PP (High PC)



Gamma = 0.65 p-value = 0.000

Perf vs. SEC-PP (Low PC)



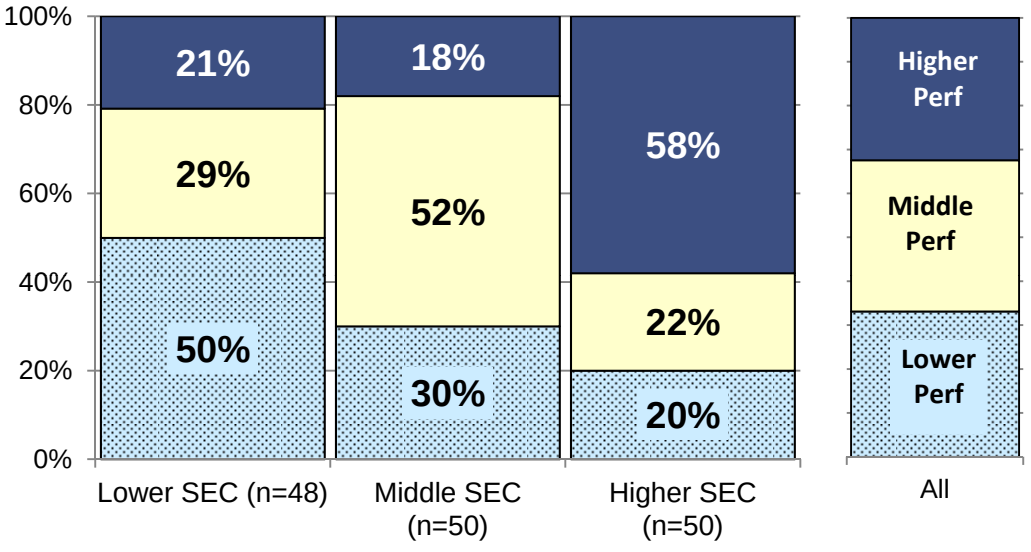
Gamma = 0.16 p-value = 0.313

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**

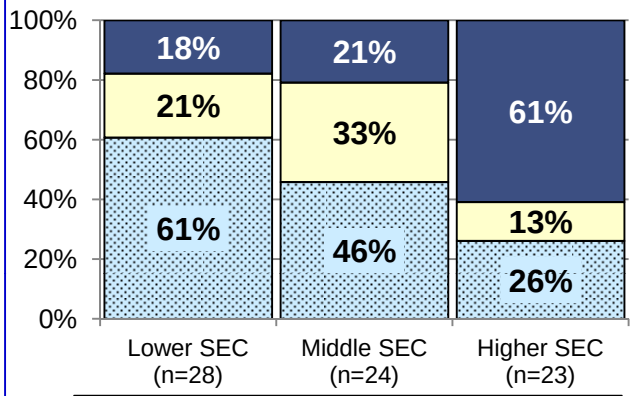
Requirements Dev't & Mg't vs. Performance

Perf vs. SEC-REQ



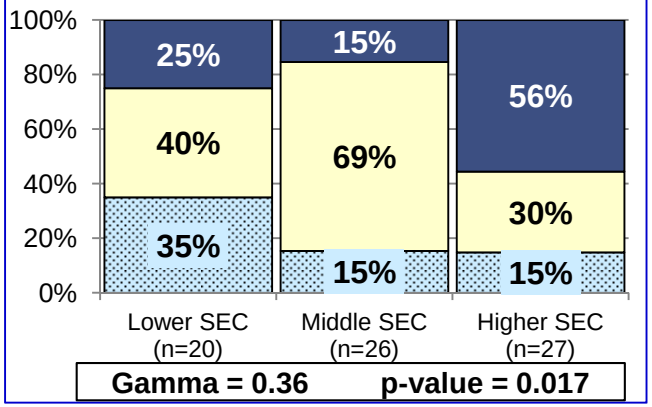
Gamma = 0.44 p-value = 0.000

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**

A Deeper Look at SE Activities

Our survey questions addressed 11 areas of SE Activities

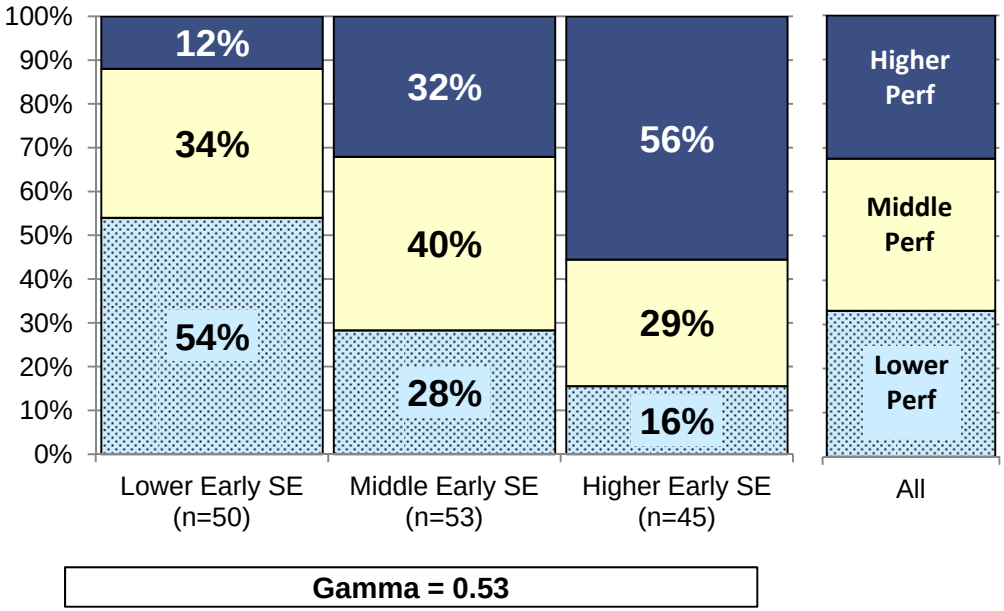
- Program Planning
- Requirements Development and Management
- Product Architecture
- Trade Studies
- Product Integration
- Verification
- Validation
- Risk Management
- Configuration Management
- Integrated Product Teams
- Program Monitoring and Control

"Early" SE

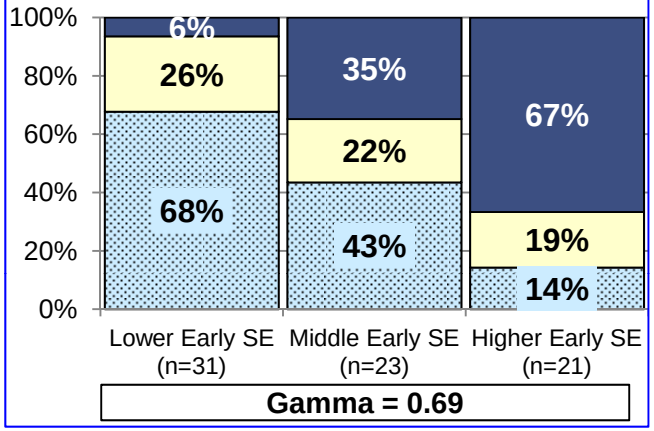
This enabled us to assess a program's deployment of SE in each of these areas

Early SE is the MOST Important

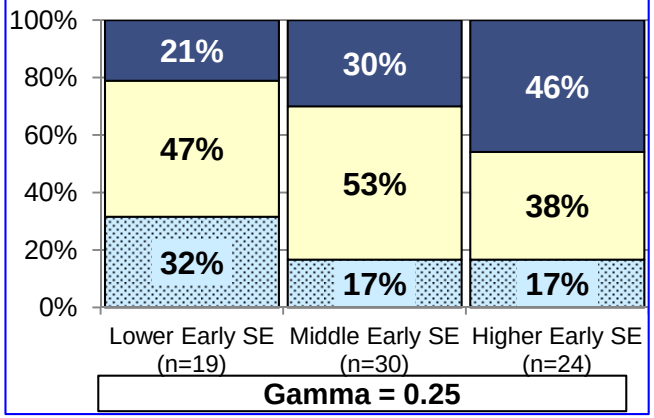
Perf vs. EarlySE



Perf vs. EarlySE (High PC)



Perf vs. EarlySE (Low PC)

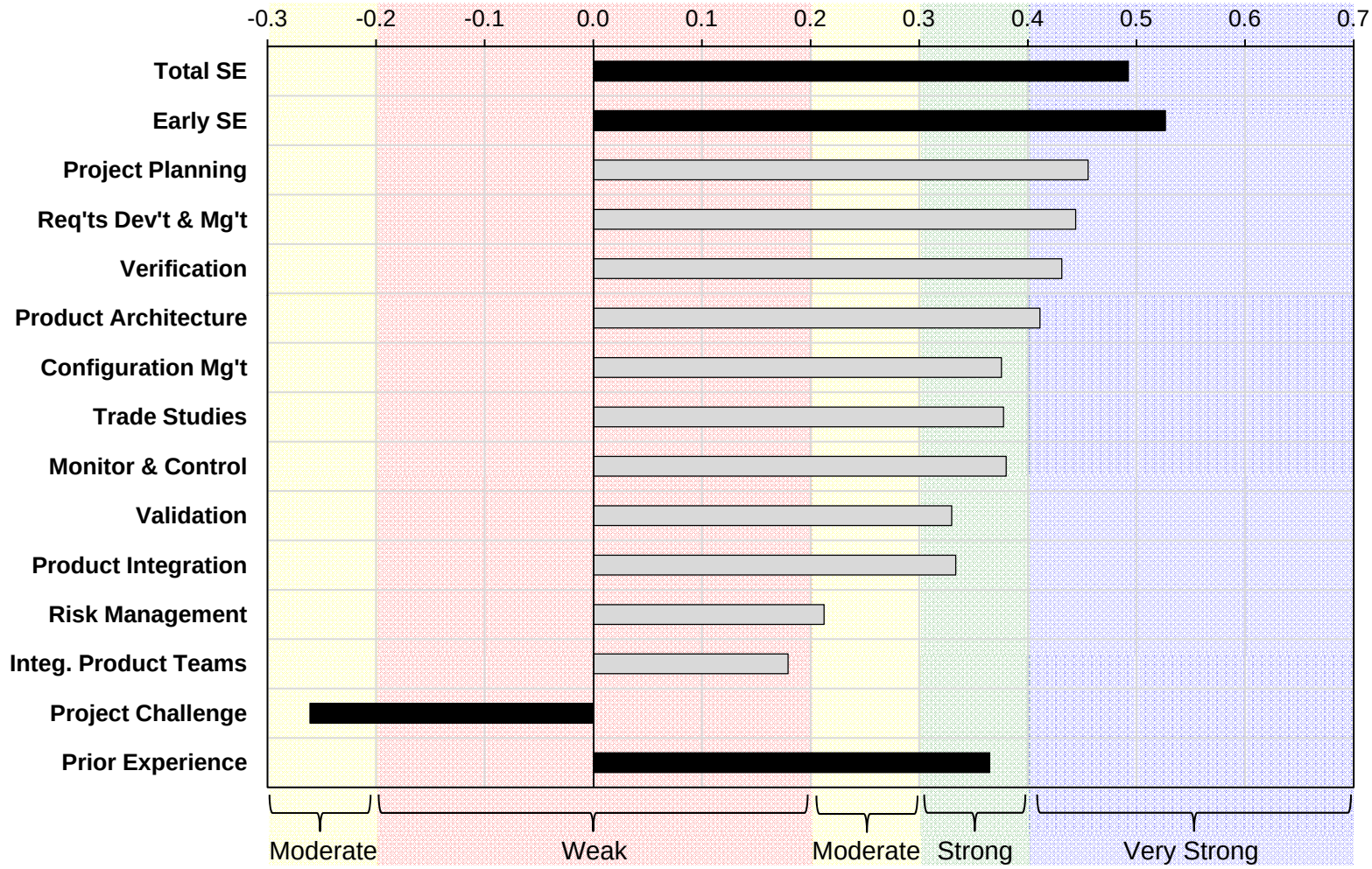


The relationship:

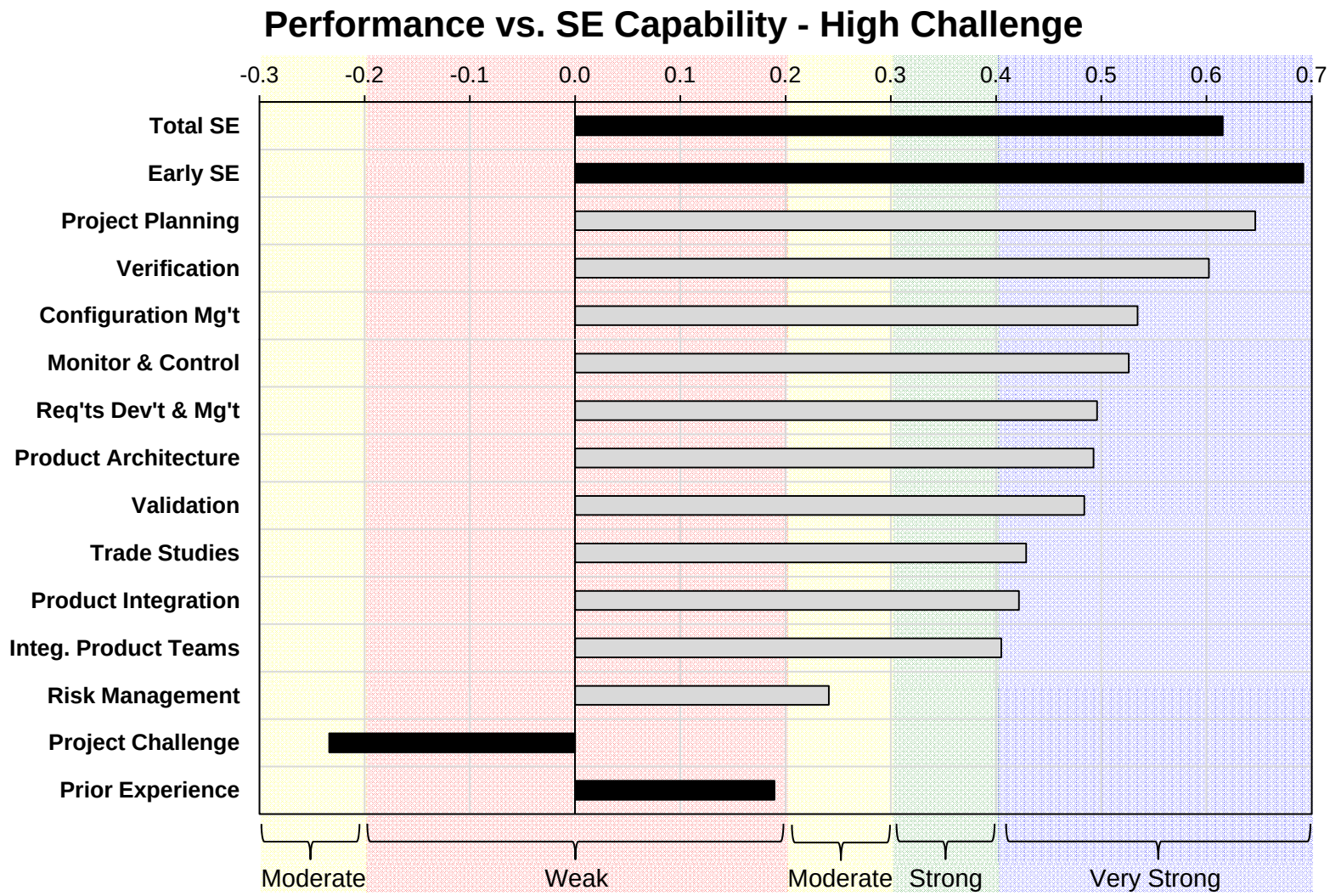
for the set of all programs	**0.53 = Very Strong**
for the set of High Challenge programs	**0.69 = Very Strong**
for the set of Low Challenge programs	**0.25 = Moderate**

Summary of Relationships

Performance vs. SE Capability - All Projects



Summary of Relationships



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

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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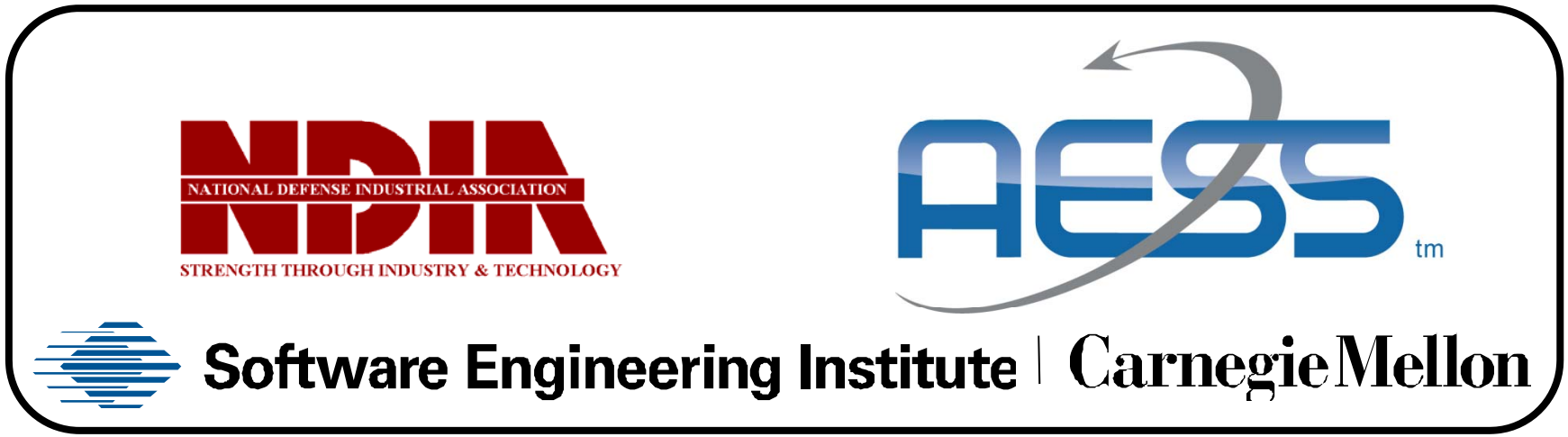
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STRENGTH THROUGH INDUSTRY & TECHNOLOGY
AESS
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BACK UP

References

Elm, J.; Goldenson, D.; El Emam, K.; Donatelli, N.; Neisa, A. "***A Survey of Systems Engineering Effectiveness – Initial Results***". Carnegie Mellon University; Pittsburgh, PA. 2007

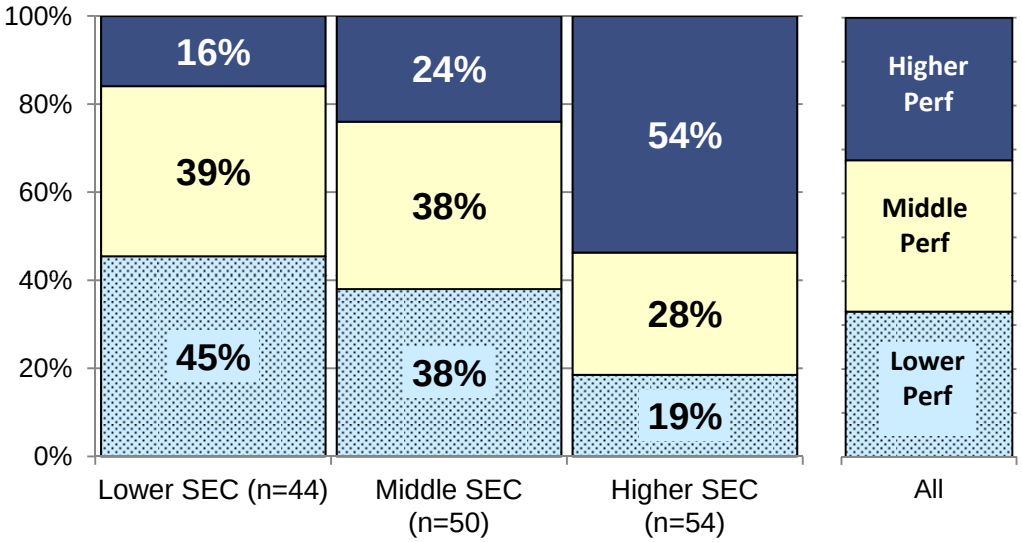
Elm, J.; Goldenson, D. "***The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey***". Carnegie Mellon University; Pittsburgh, PA 2012 (available at http://www.sei.cmu.edu/library/abstracts/reports/12sr009.cfm)

Gruhl, W. "***Lessons Learned, Cost/Schedule Assessment Guide***" Internal Presentation (unpublished), NASA Comptrollers office. 1992

Honour, E., "**Systems Engineering Return on Investment**" PhD thesis, Defence and Systems Institute, University of South Australia. 2013 http://www.hcode.com/secoe

Verification vs. Performance

Perf vs. SEC-VER

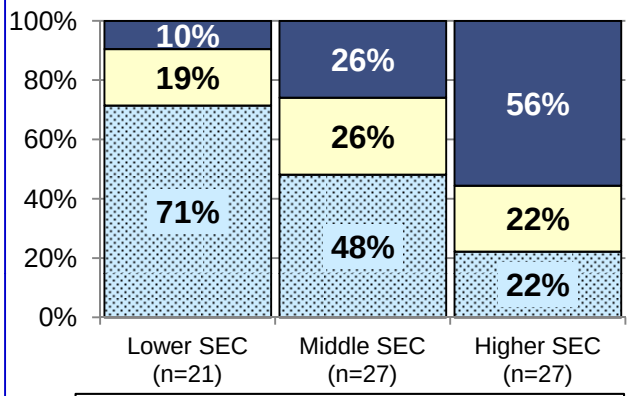


Gamma = 0.43 p-value = 0.000

The relationship:

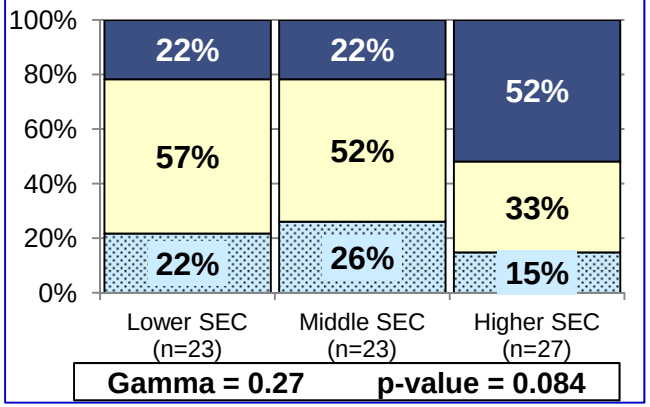
for the set of all programs	**0.43 = Very Strong**
for the set of High Challenge programs	**0.60 = Very Strong**
for the set of Low Challenge programs	**0.27 = Moderate**

Perf vs. SEC-VER (High PC)



Gamma = 0.6 p-value = 0.000

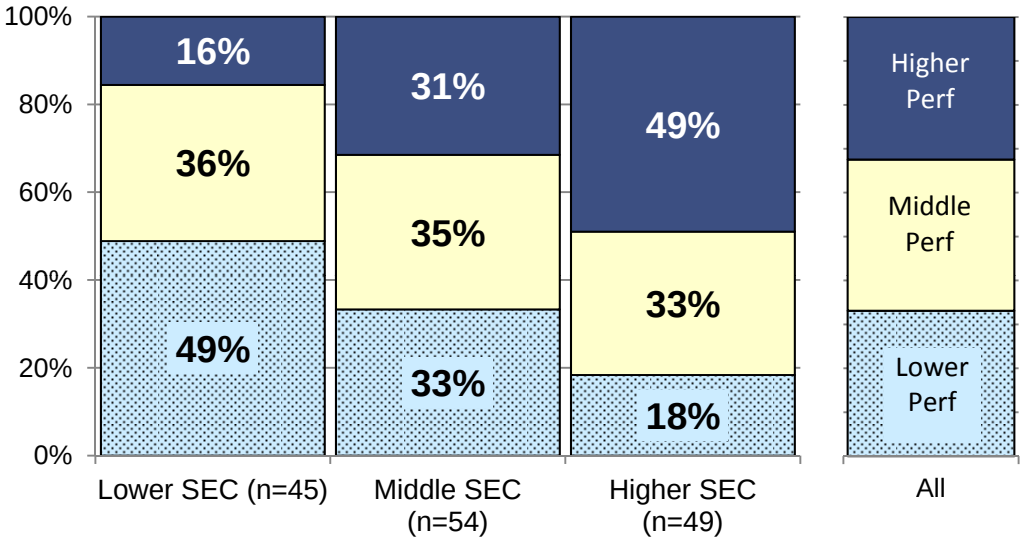
Perf vs. SEC-VER (Low PC)



Gamma = 0.27 p-value = 0.084

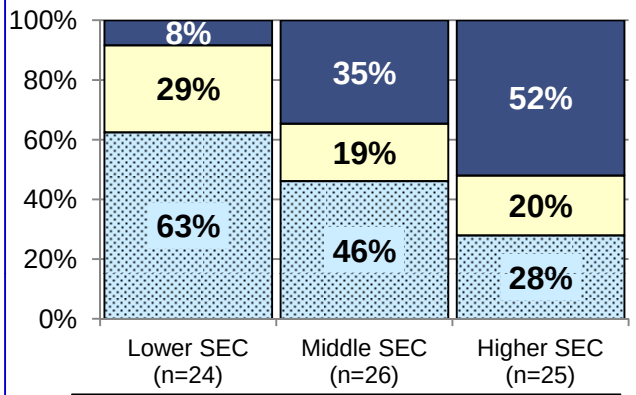
Architecture vs. Performance

Perf vs. SEC-ARCH



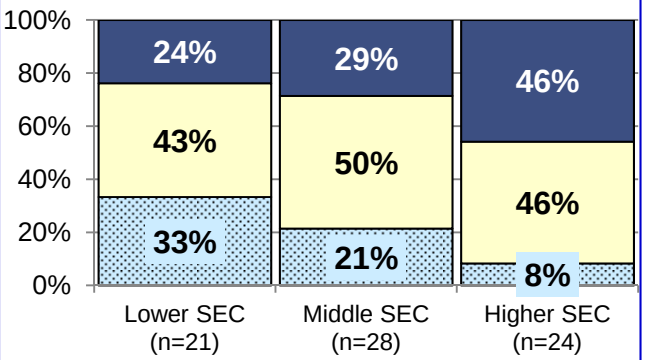
Gamma = 0.41 p-value = 0.000

Perf vs. SEC-ARCH (High PC)



Gamma = 0.49 p-value = 0.001

Perf vs. SEC-ARCH (Low PC)



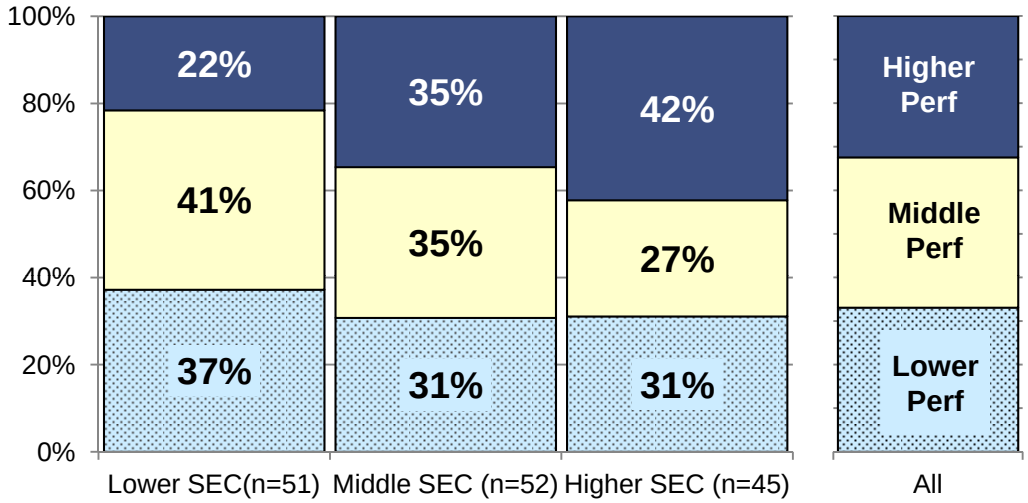
Gamma = 0.31 p-value = 0.051

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**

Integrated Product Teams vs. Performance

Perf vs. SEC-IPT

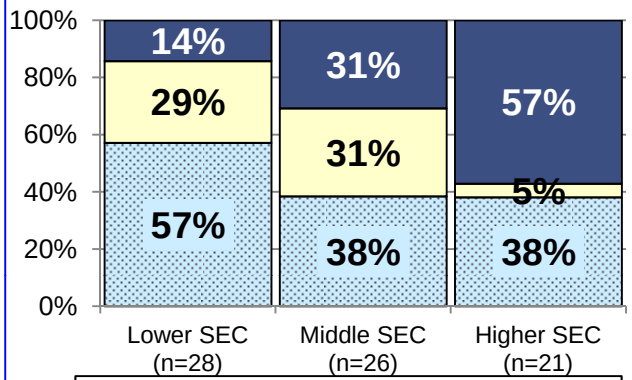


Gamma = 0.18 p-value = 0.101

The relationship:

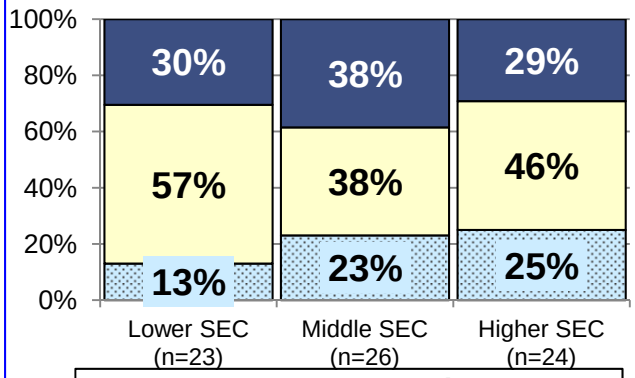
for the set of all programs	**0.18 = Weak**
for the set of High Challenge programs	**0.40 = Strong**
for the set of Low Challenge programs	**-0.12 = Weak Neg.**

Perf vs. SEC-IPT (High PC)



Gamma = 0.4 p-value = 0.007

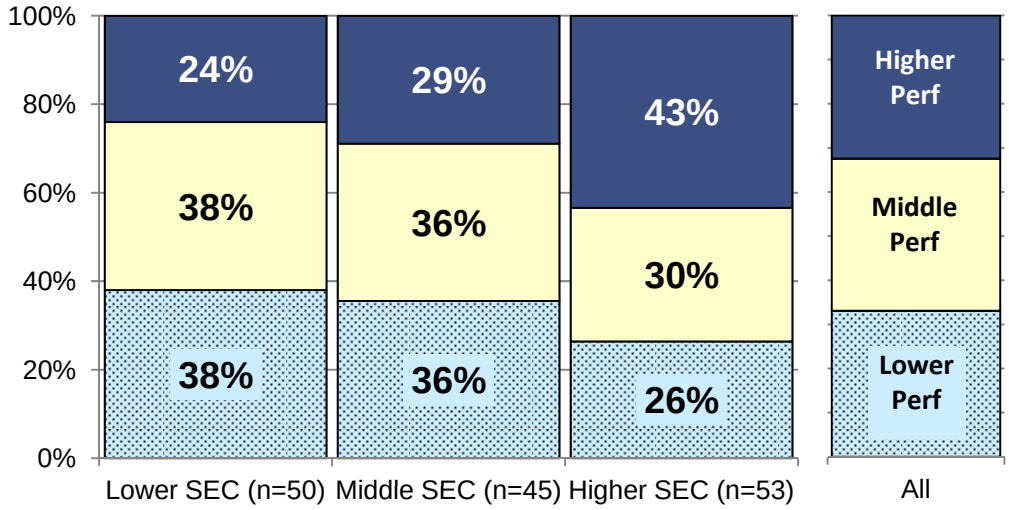
Perf vs. SEC-IPT (Low PC)



Gamma = -0.12 p-value = 0.436

Risk Management vs. Performance

Perf vs. SEC-RSKM

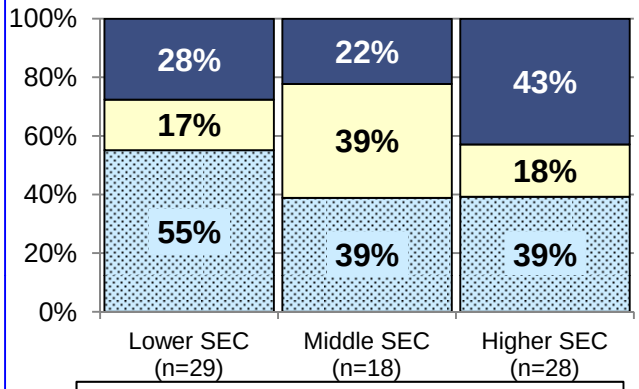


Gamma = 0.21 p-value = 0.05

The relationship:

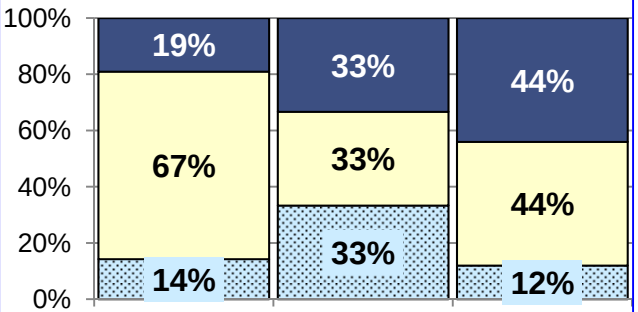
for the set of all programs	**0.21 = Moderate**
for the set of High Challenge programs	**0.24 = Moderate**
for the set of Low Challenge programs	**0.18 = Weak**

Perf vs. SEC-RSKM (High PC)



Gamma = 0.24 p-value = 0.124

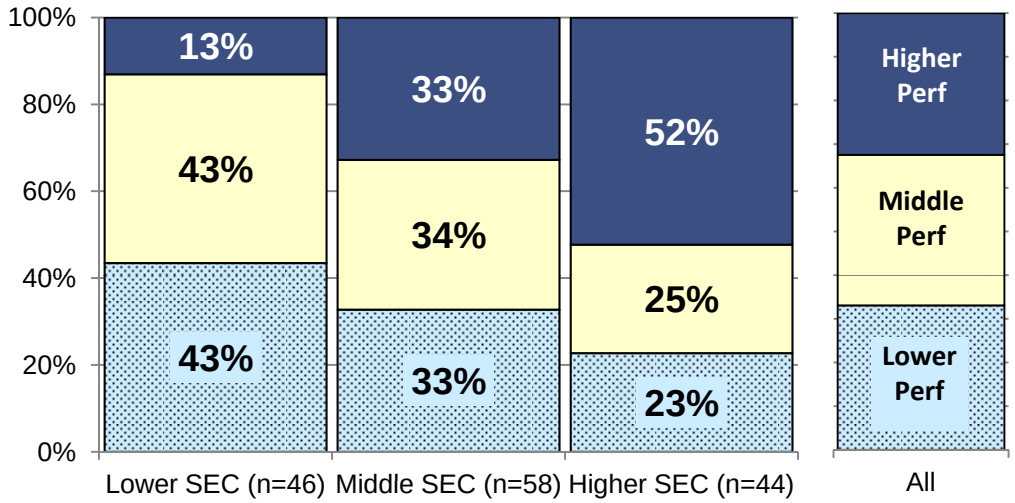
Perf vs. SEC-RSKM (Low PC)



Gamma = 0.18 p-value = 0.256

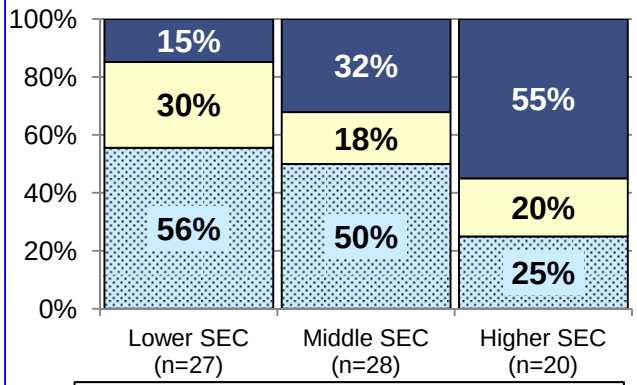
Trade Studies vs. Performance

Perf vs. SEC-TRD



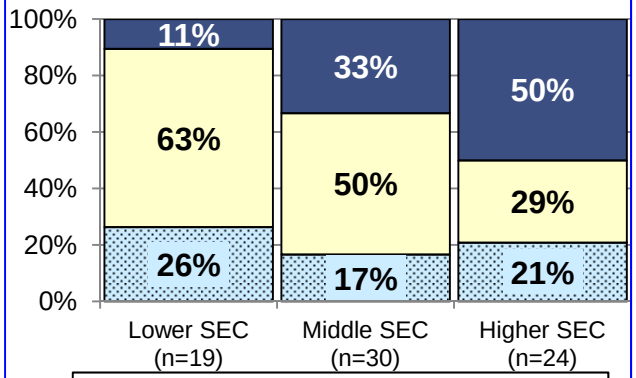
Gamma = 0.38 p-value = 0

Perf vs. SEC-TRD (High PC)



Gamma = 0.43 p-value = 0.004

Perf vs. SEC-TRD (Low PC)



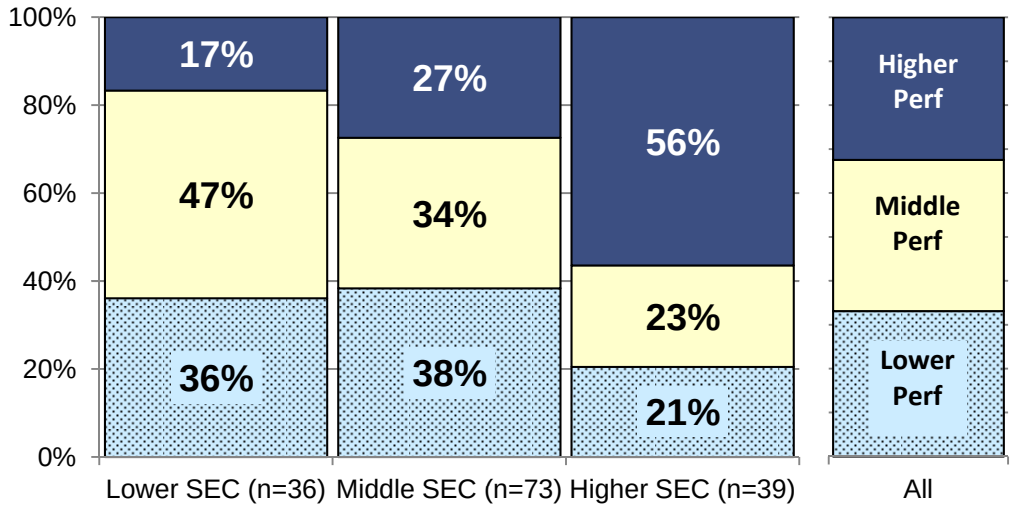
Gamma = 0.29 p-value = 0.062

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**

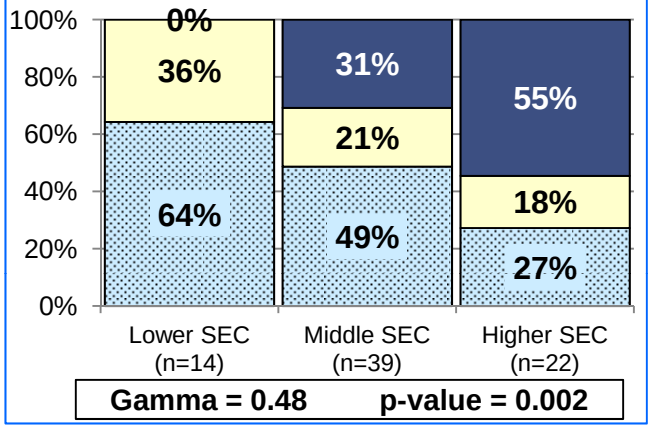
Validation vs. Performance

Perf vs. SEC-VAL



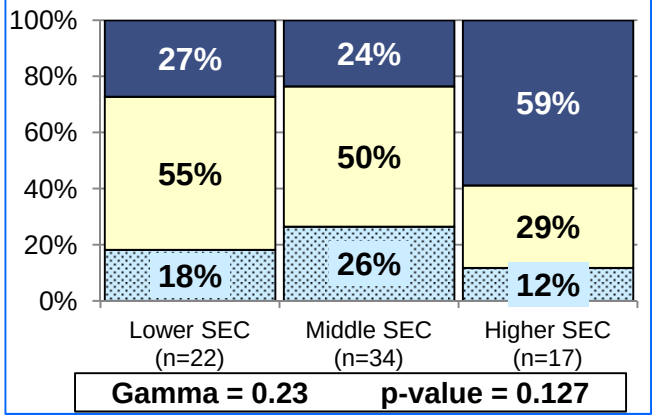
Gamma = 0.33 p-value = 0.003

Perf vs. SEC-VAL (High PC)



Gamma = 0.48 p-value = 0.002

Perf vs. SEC-VAL (Low PC)



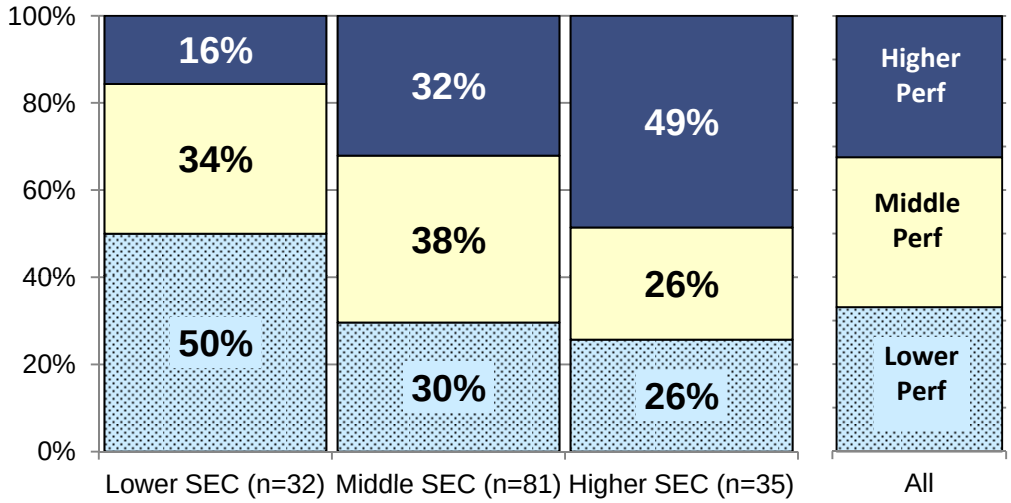
Gamma = 0.23 p-value = 0.127

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**

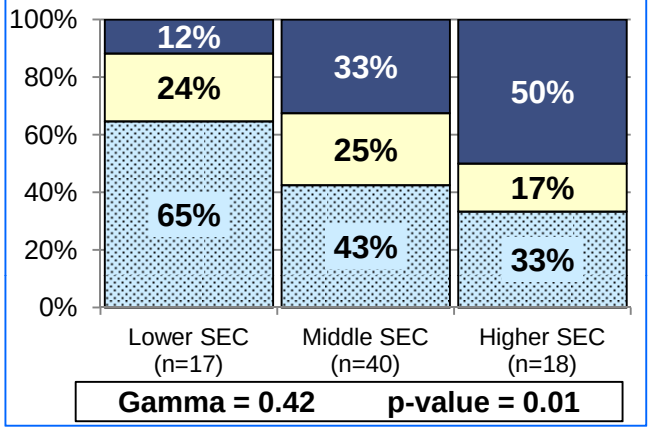
Product Integration vs. Performance

Perf vs. SEC-PI



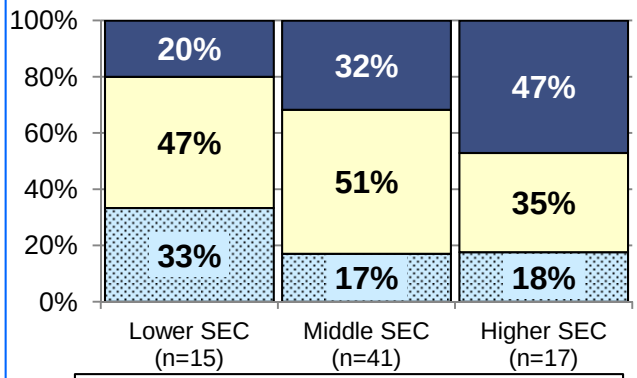
Gamma = 0.33 p-value = 0.003

Perf vs. SEC-PI (High PC)



Gamma = 0.42 p-value = 0.01

Perf vs. SEC-PI (Low PC)



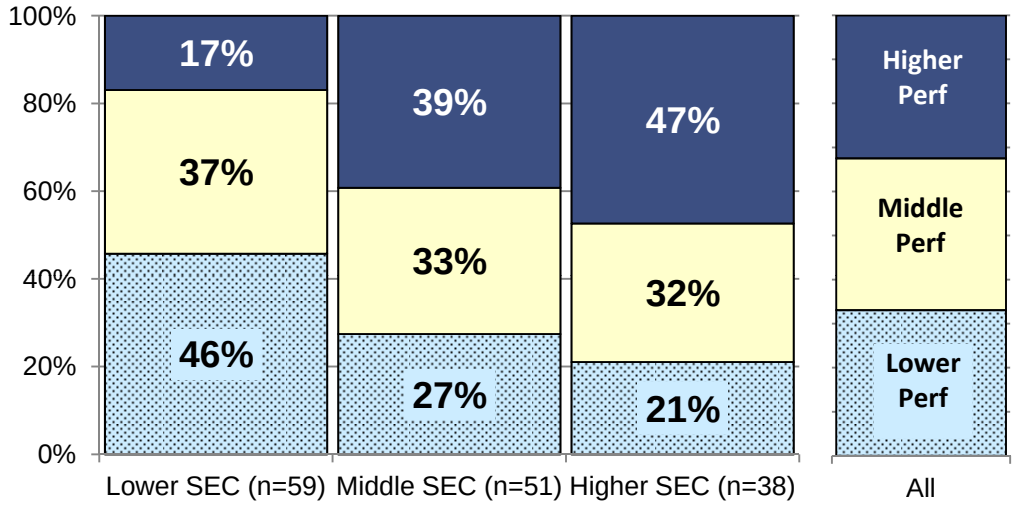
Gamma = 0.23 p-value = 0.153

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**

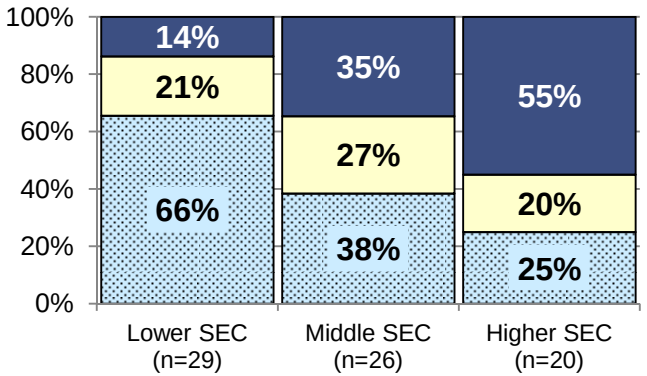
Configuration Management vs. Performance

Perf vs. SEC-CM



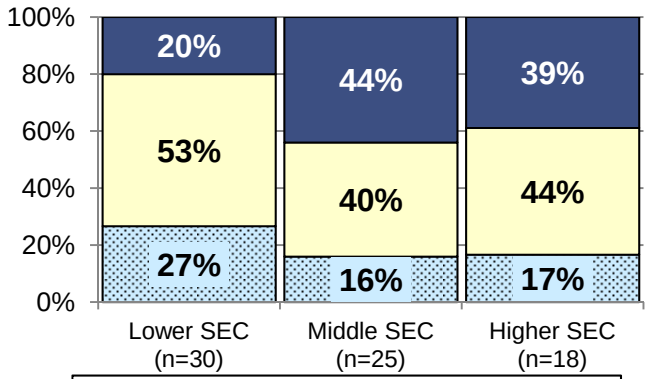
Gamma = 0.38 p-value = 0.001

Perf vs. SEC-CM (High PC)



Gamma = 0.53 p-value = 0

Perf vs. SEC-CM (Low PC)



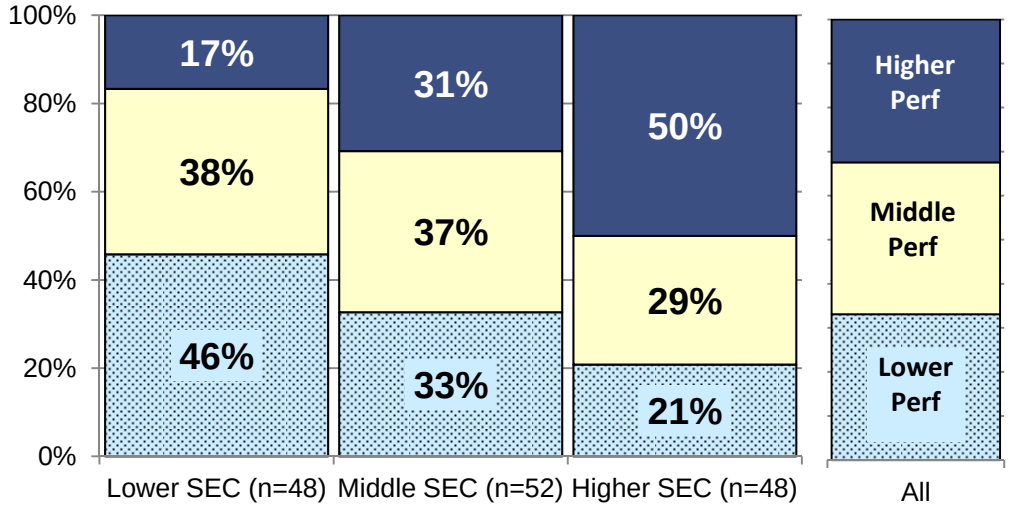
Gamma = 0.22 p-value = 0.203

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**

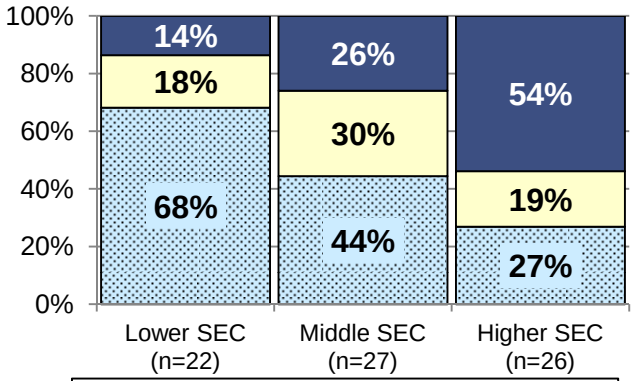
Program Monitoring & Control vs. Performance

Perf vs. SEC-PMC



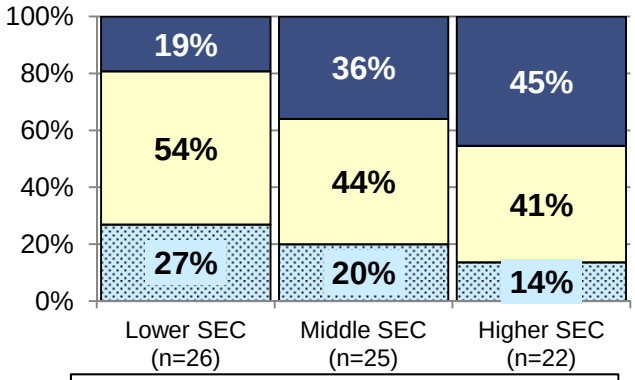
Gamma = 0.38 p-value = 0

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**