



## Leveraging Systems Engineering to Improve Project Performance

Narration provided in  
“PRESENTATION” mode

**NDIA Systems Engineering Division  
Systems Engineering Effectiveness Committee**

Presented by: Joseph P. Elm  
Software Engineering Institute



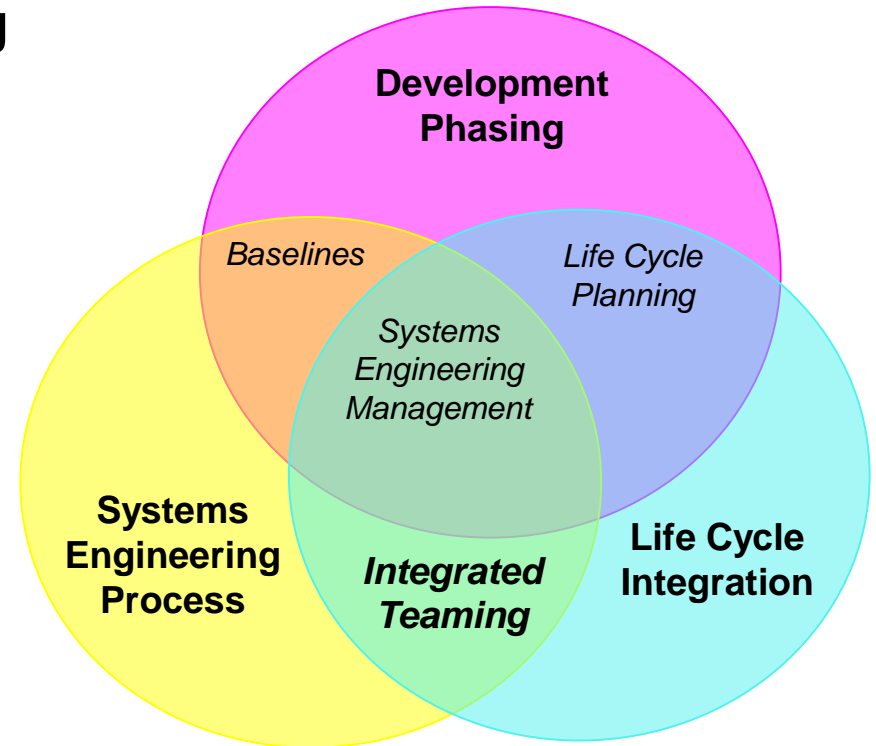
# Agenda

▶ The Need for Systems Engineering

The NDIA Systems Engineering Effectiveness Study (SEES)

Survey Results

Using the Results



# 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

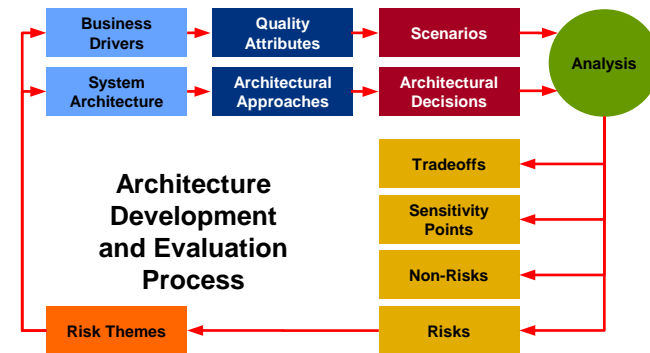
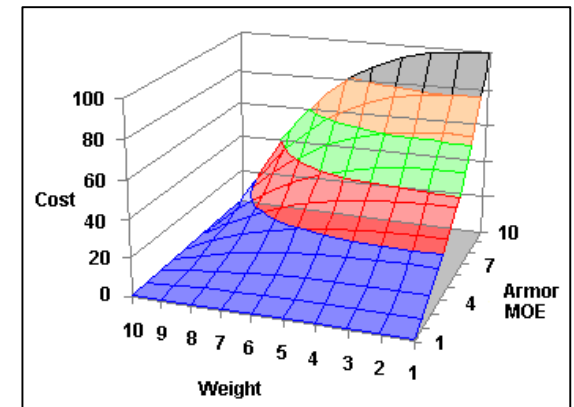
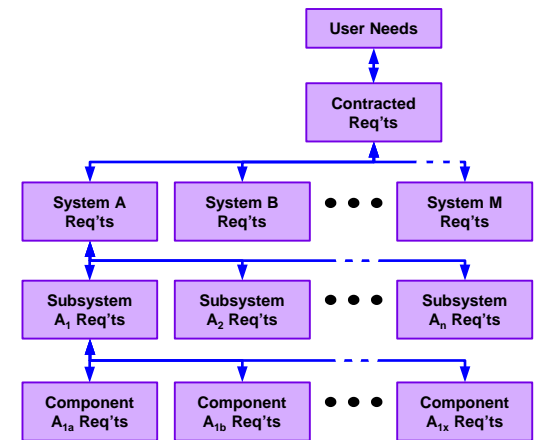
- Decomposition of requirements
- Allocation of requirements among multiple systems

## 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
- Project Planning
- Project Monitoring and Control
- Risk Management
- Product Integration Planning and Oversight
- Verification Planning and Oversight
- Validation Planning and Oversight

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

\* Some tasks are done in partnership with the Project Manager



# Does this sound familiar?

**The SE efforts on my project are critical because they ...**

- ... pay off in the end.
- ... ensure that stakeholder requirements are identified and addressed.
- ... provide a way to manage project 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 project 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 is difficult to justify the costs of SE in terms that project 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 project performance?**





# The Solution

Obtain quantitative evidence of the costs and associated benefits of Systems Engineering activities via a survey of development projects



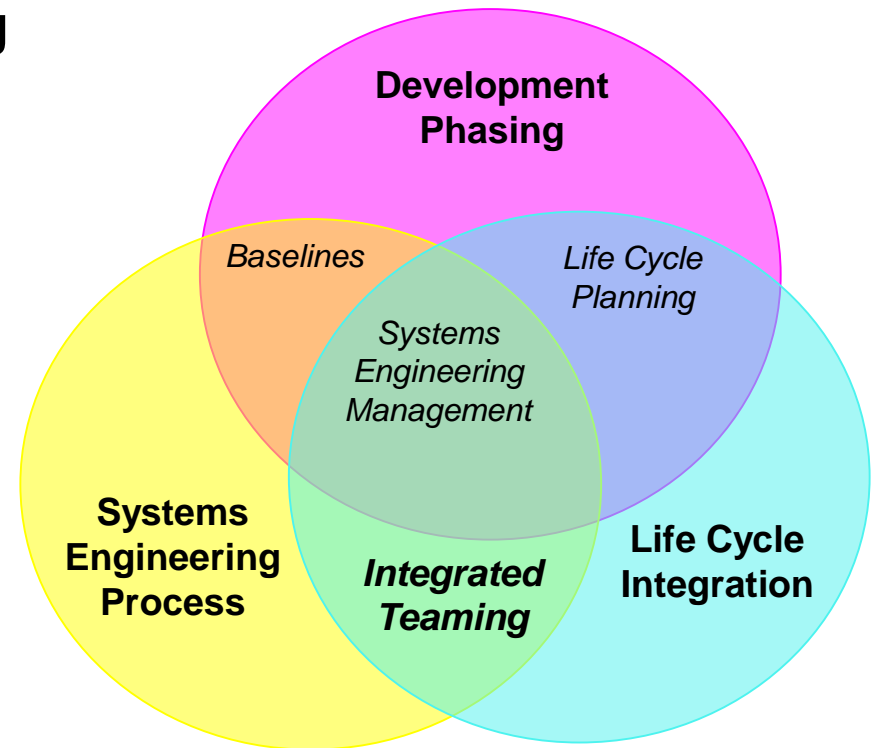
# Agenda

The Need for Systems Engineering

▶ The NDIA Systems Engineering Effectiveness Study (SEES)

Survey Results

Using the Results



# Survey Hypothesis

The effective performance of SE best practices on a development project yields quantifiable improvements in the project execution (e.g., improved cost performance, schedule performance, technical performance).



# The NDIA Systems Engineering Effectiveness Study (SEES)

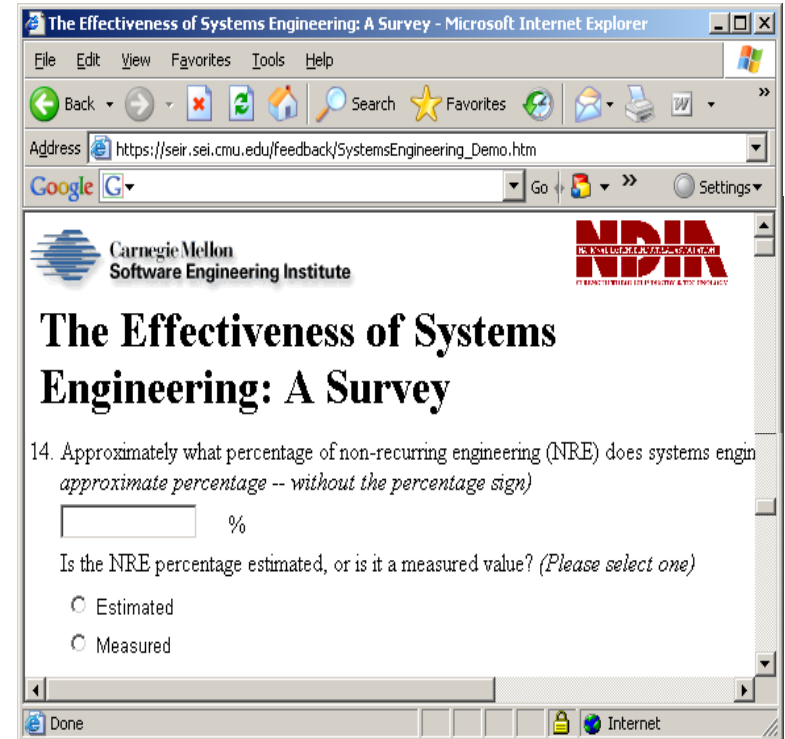
Performed by NDIA in conjunction with the SEI in 2006-2007

Surveyed 64 projects at defense contractors to assess:

- Characteristics of individual projects (e.g., complexity, size, environment)
- Specific SE practices applied to each project
- The performance of each project, as measured by conformance to budget, schedule, and requirements satisfaction

**Data protection was paramount**

- Data was collected anonymously to ensure confidentiality and encourage honest and accurate reporting
- Response data only accessible by key SEI staff
- Only aggregated results made public - untraceable to any project, person or organization



Results published at:

<http://www.sei.cmu.edu/publications/documents/08.reports/08sr034.html>



# Assessment of SE Practices 1

## Question #1

What SE activities do you apply to your project?

### Challenge

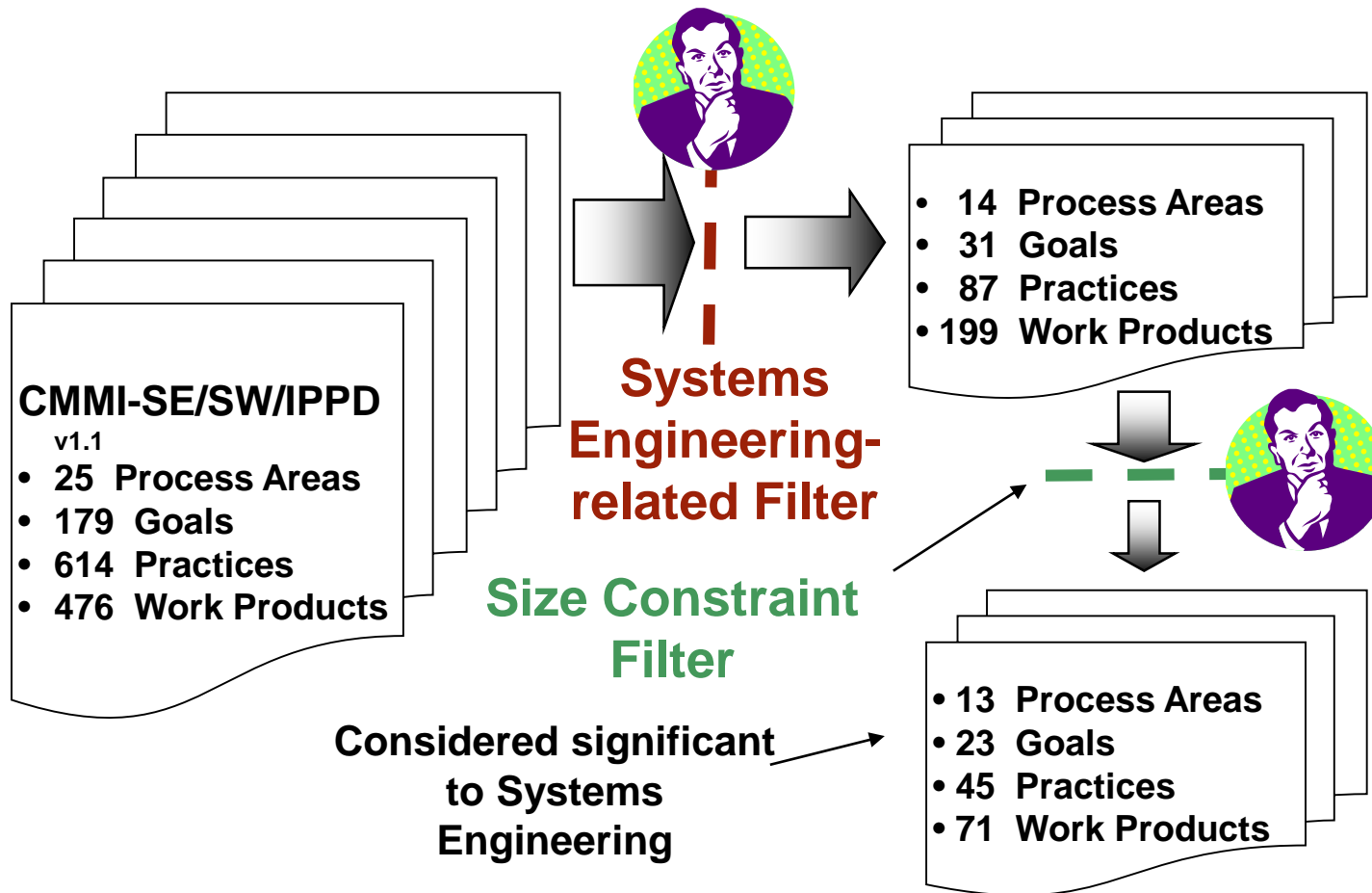
- No generally accepted definition of what IS and what IS NOT a part of SE.
  - “How much SE do you do on your project?” ← No answer
- SE is often embedded in other tasks and not budgeted separately
  - “How much does your project spend on SE?” ← No answer

### Solution

- Avoid a defining SE
  - Too much controversy
- Ask about the results of activities that are generally agreed to be SE



# Assessment of SE Practices 2



Survey content is based on a recognized standard (CMMI)



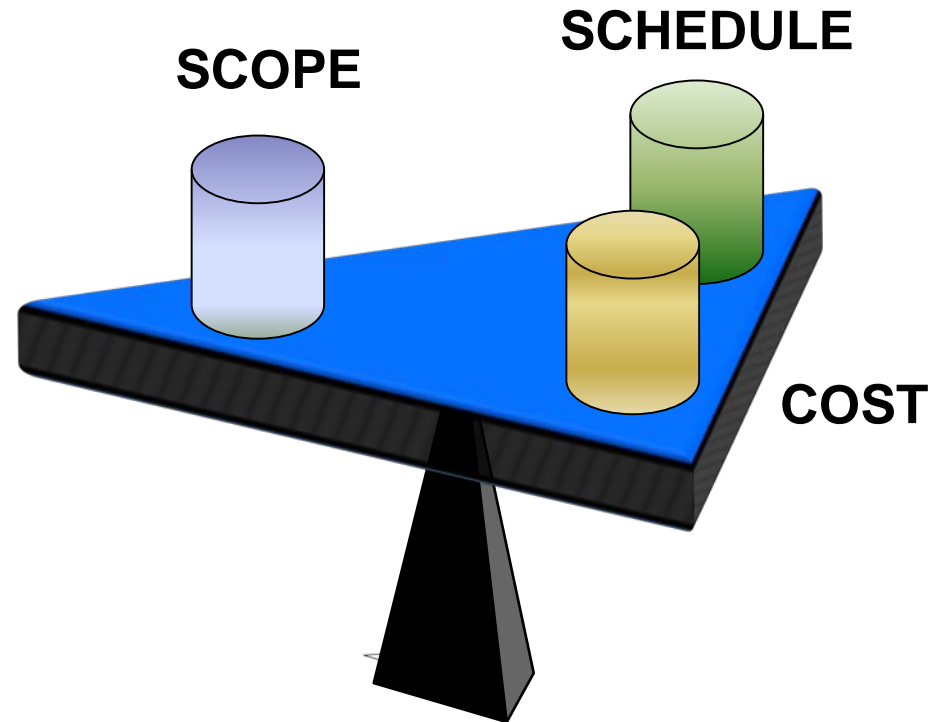
# Assessment of Project Performance

## Address TOTAL Project Performance

- Project Cost
- Project Schedule
- Project Scope

## Focus on commonly used measurements

- Earned Value Management (CPI, SPI, baseline management)
- Requirements satisfaction
- Budget re-baselining and growth
- Milestone and delivery satisfaction



# Assessment of Other Factors

## Question #3

What other factors affect project performance?

**SE Capability is not the ONLY thing that can impact Project Performance. What about:**

- **Project Challenge** – some projects are more complex than others
  - Lifecycle scope, technology maturity, interoperability needs, precedence, size, duration, organizational complexity, quality of definition
- **Acquirer Capability** – some acquirers are more capable than others
  - Requirements quality, acquirer engagement, consistency of direction
- **Project Environment** – projects executed in and deployed to different environments have different needs
  - Acquiring organization, user organization, deployment environment, contract type, developer's experience, developer's process quality





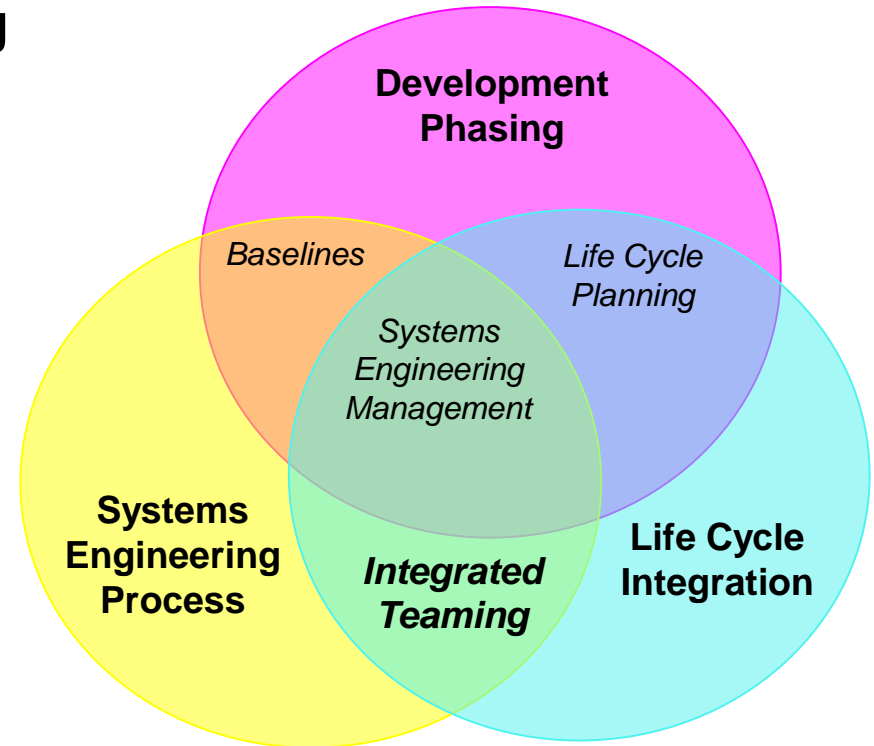
# Agenda

The Need for Systems Engineering

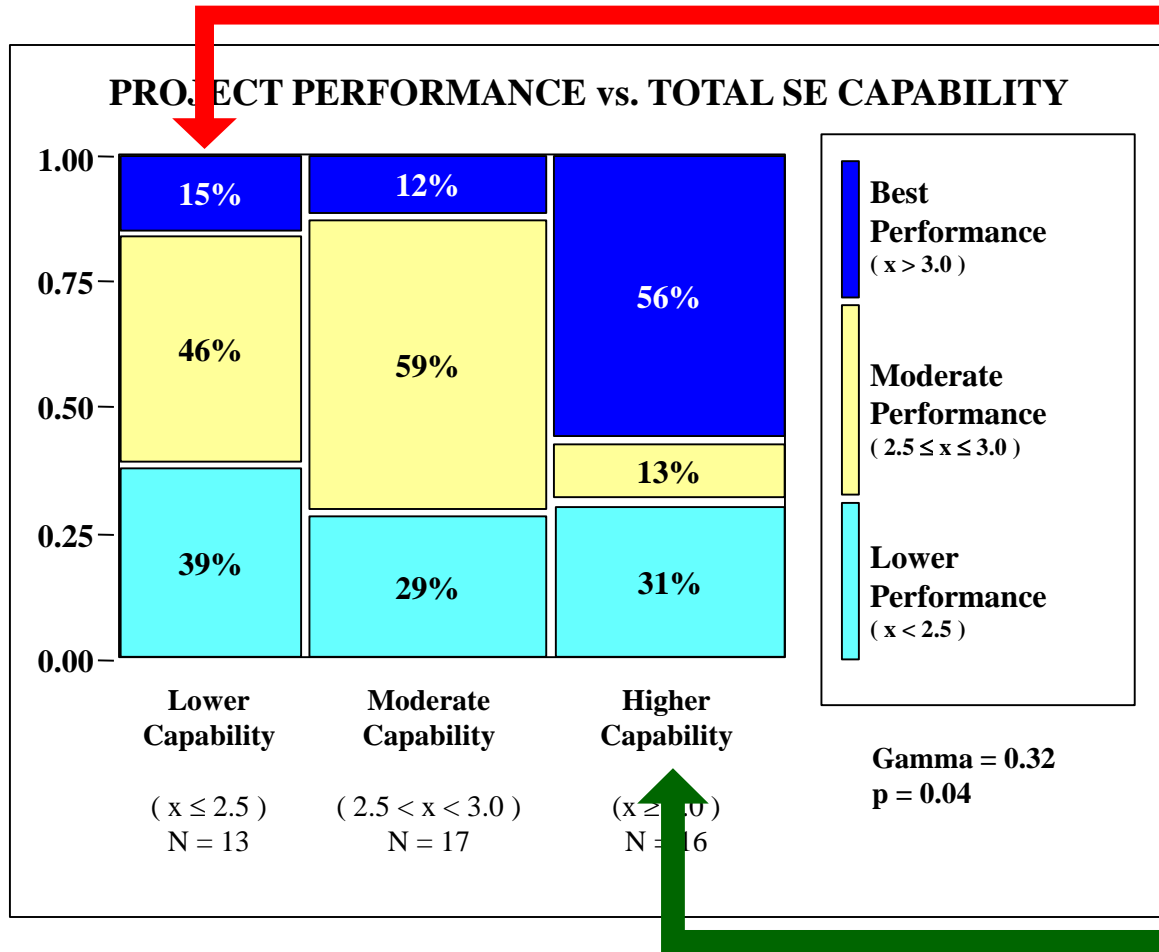
The NDIA Systems Engineering Effectiveness Study (SEES)

Survey Results

Using the Results



# The Bottom Line <sub>1</sub>

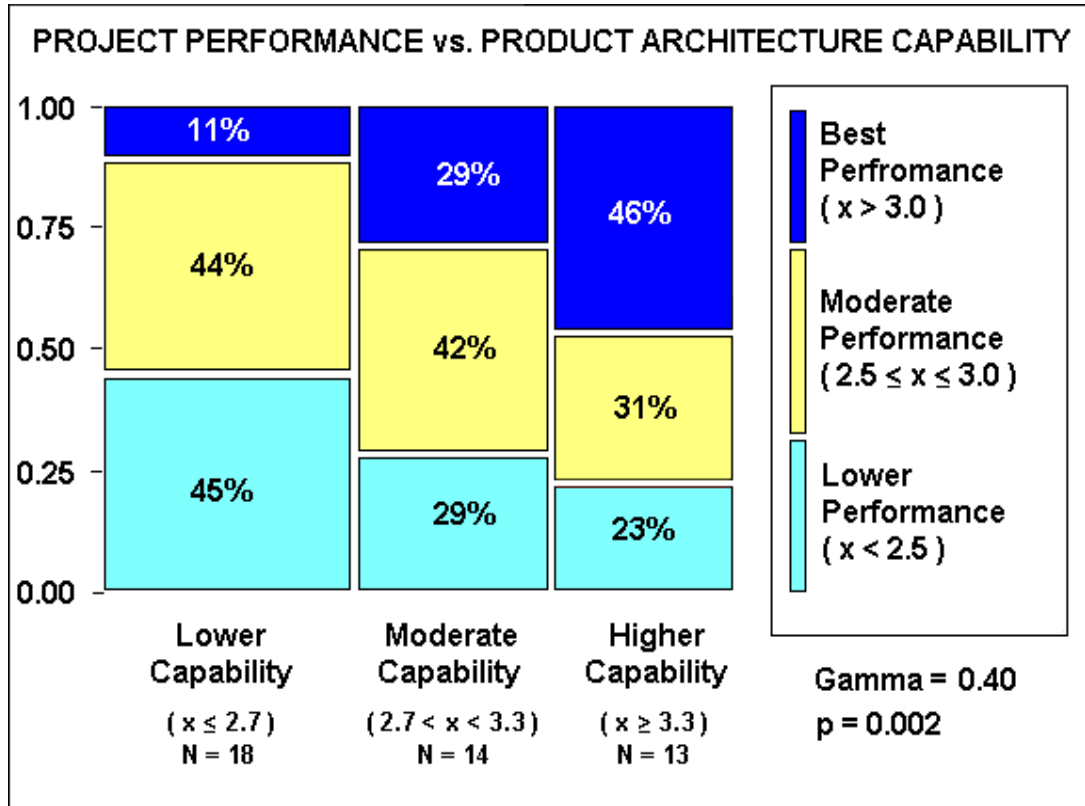


For the projects that did the least SE, only **15%** delivered the best project performance.

For the projects that did the most SE, **56%** delivered the best project performance



# Product Architecture Capability vs. Project Performance



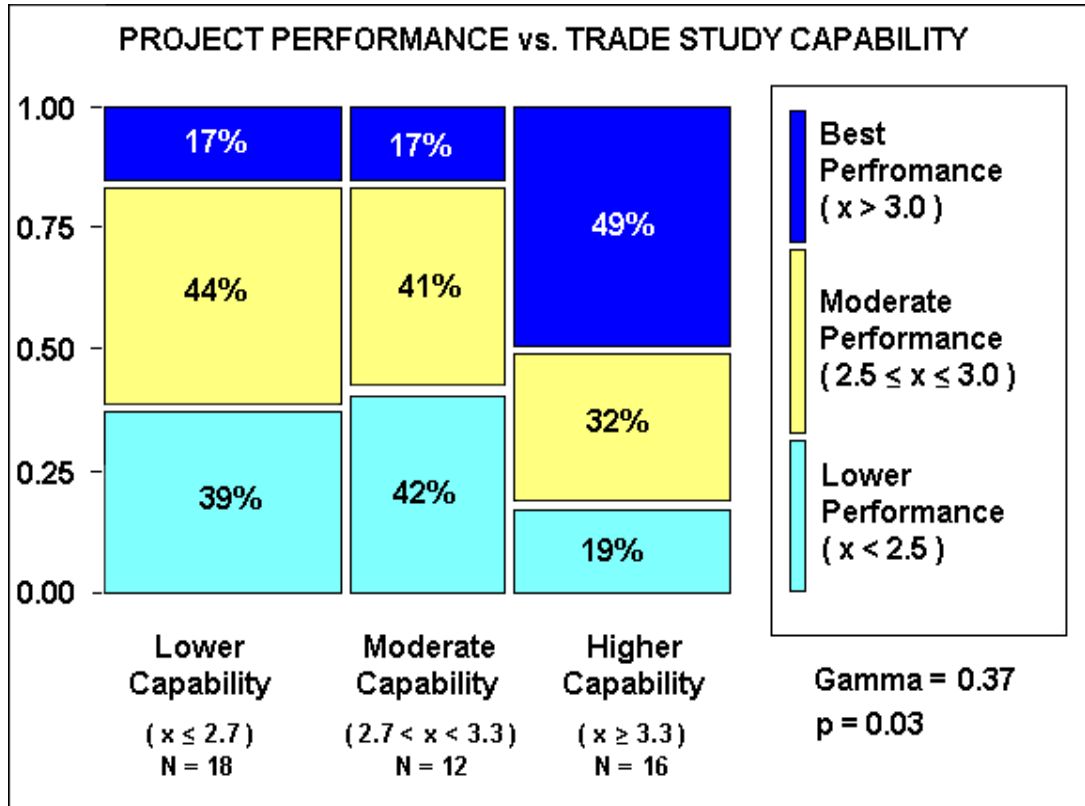
## Product architecture assessment examined

- High-level product structure documentation
  - Including multiple views
- Interface Descriptions

Better Product Architecture has a “Moderately Strong / Strong” **positive** relationship with Better Performance



# Trade Study Capability vs. Project Performance



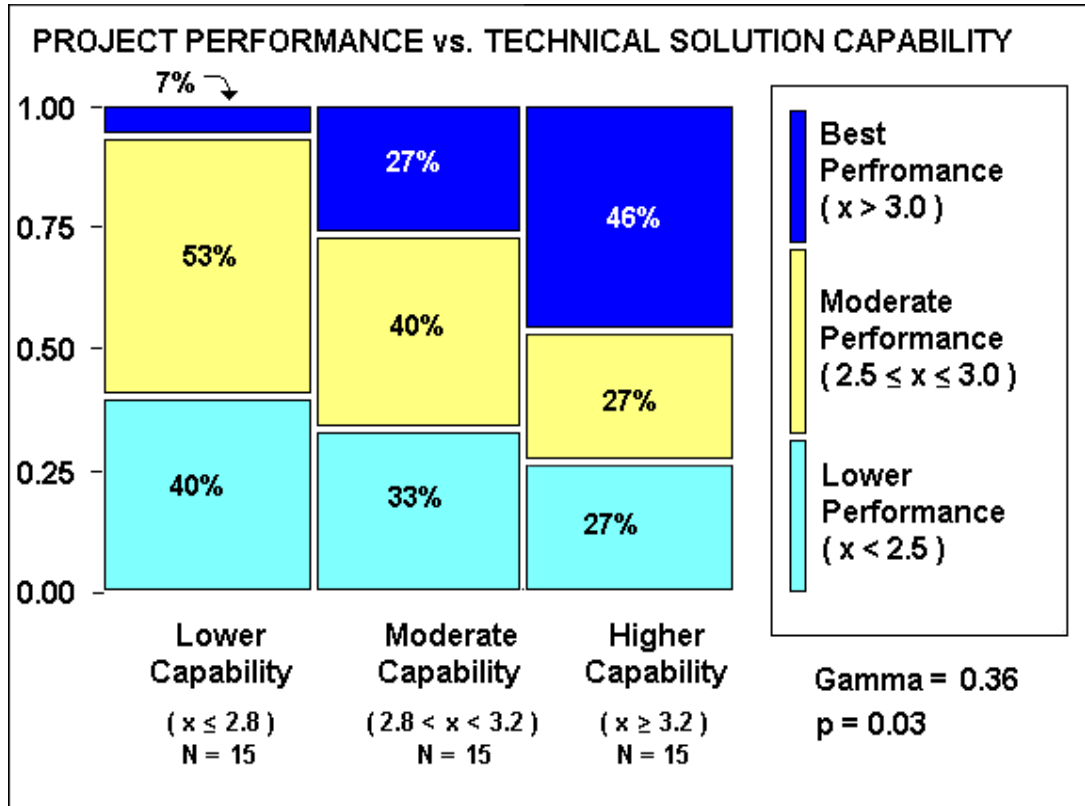
## Trade Study assessment examined

- Documentation of Trade Study selection criteria
- Documentation of Trade Study results
- Stakeholder involvement

Better Trade Studies have a “Moderately Strong / Strong” **positive** relationship with Better Performance



# Technical Solution Capability vs. Project Performance

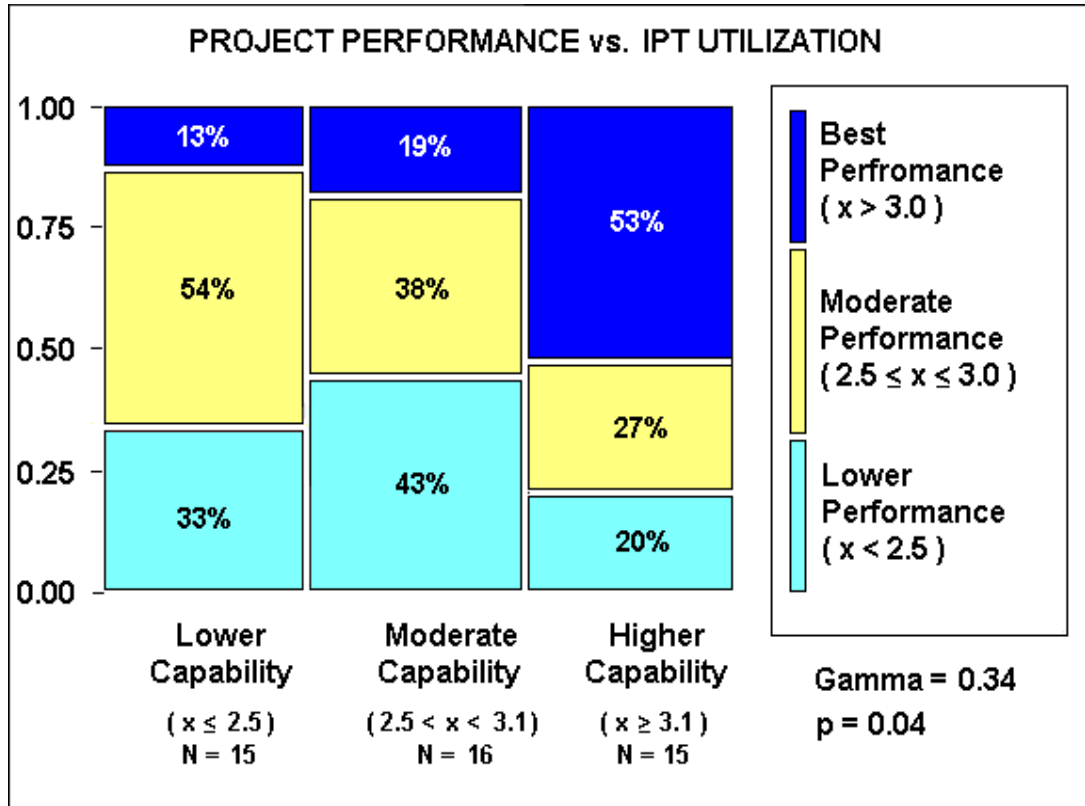


Technical Solution performance is the combination of both Product Architecture and Trade Study performance

Better Technical Solution processes have a “Moderately Strong” **positive** relationship with Better Performance



# IPT Utilization vs. Project Performance



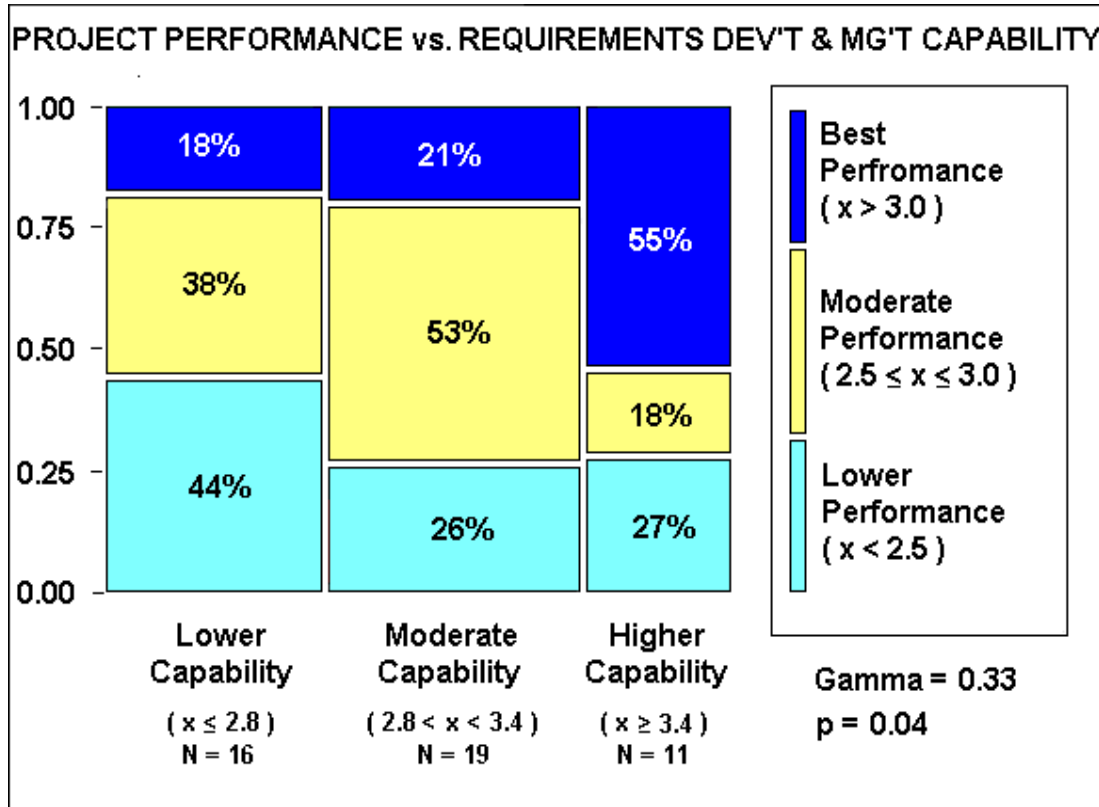
## IPT (Integrated Product Team) assessment examined

- Effective IPT Usage on Project
- Supplier participation
- IPT for Systems Engineering
- SE Representation on each IPT

Better IPT Deployment has a “Moderately Strong” **positive** relationship with Better Performance



# Requirements Development & Management vs. Project Performance



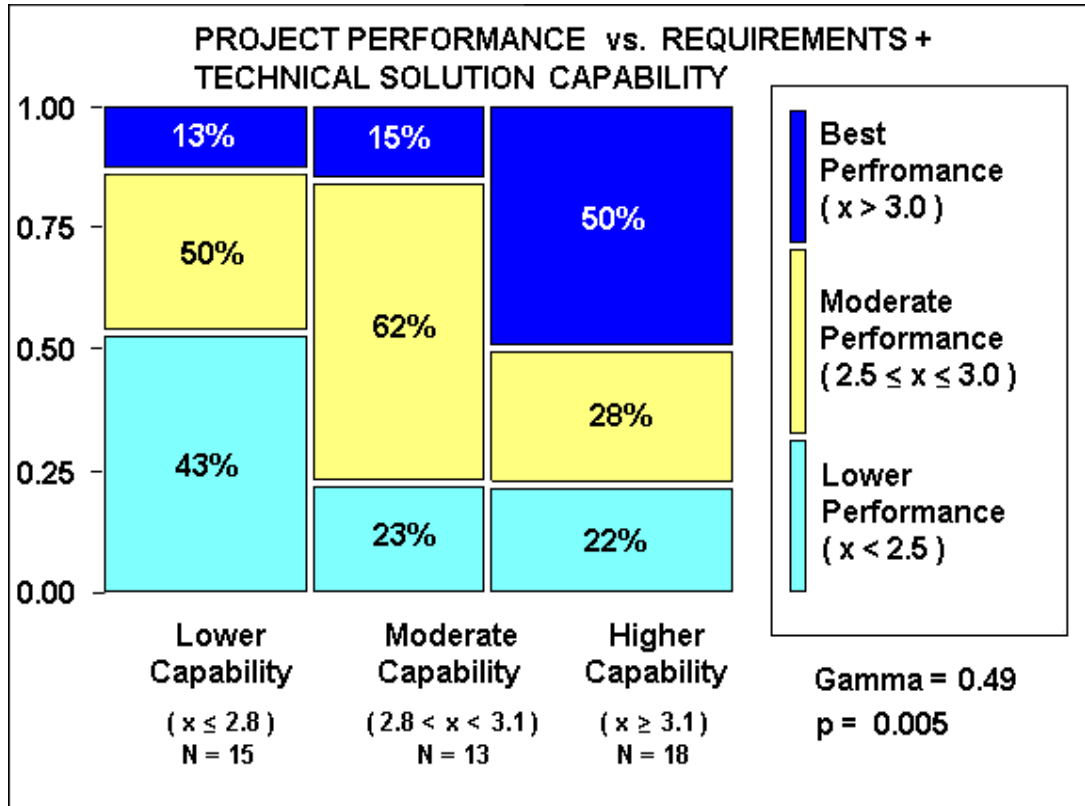
## Requirements assessment examined

- Customer & derived requirements lists
- Hierarchical allocation to system elements
- CONOPs, scenarios, and Use cases
- Criteria for authorization of req'ts providers and acceptance of req'ts
- Change control process
- Traceability to Stakeholder needs

Better Requirements Development and Management has a “Moderately Strong” **positive** relationship with Better Performance



# Requirements + Technical Solution Capability vs. Project Performance



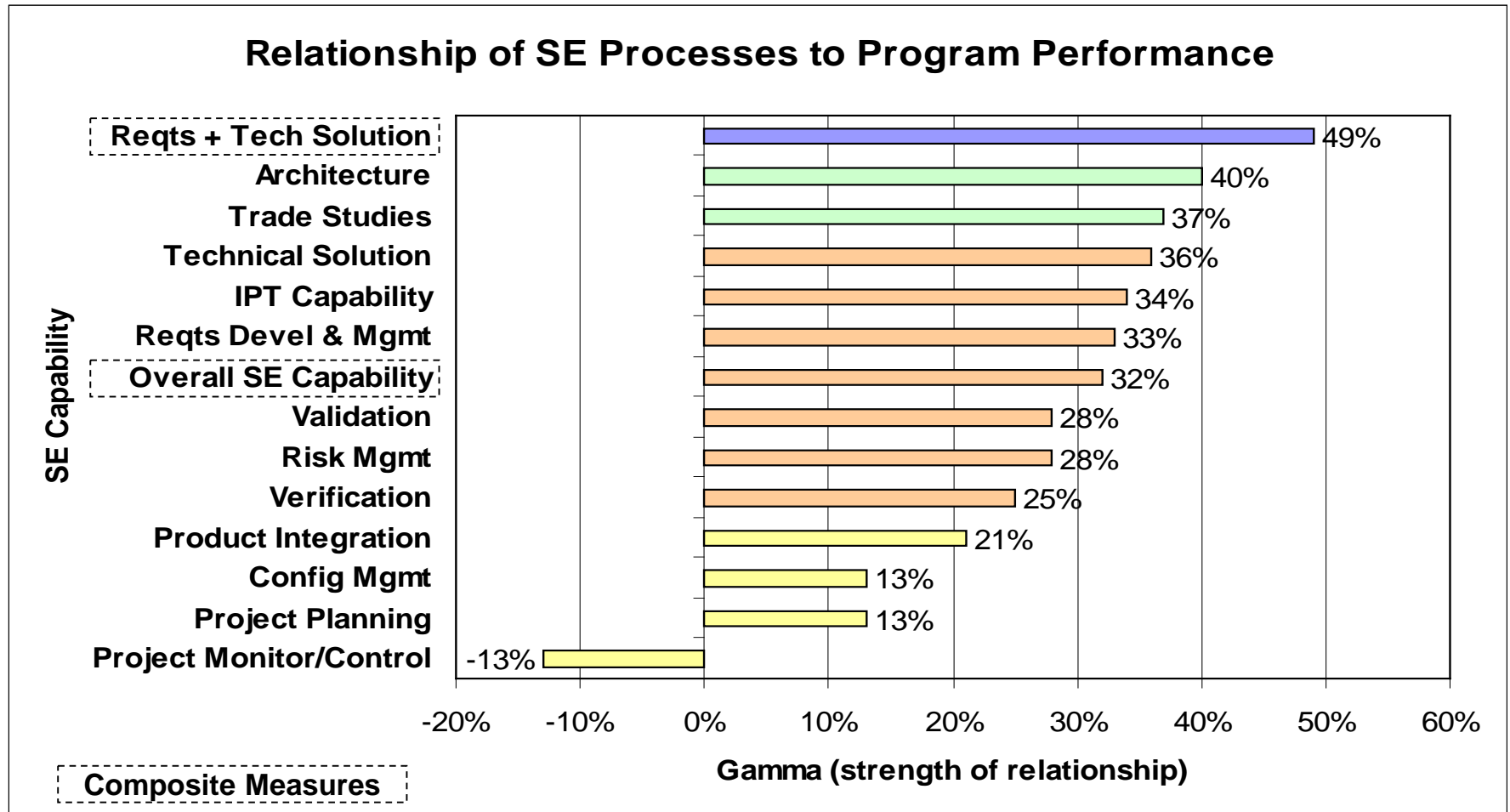
When looking at the impact of **COMBINED SE activities**, we see even stronger relationships

Better Requirements Dev't & Mg't and Better Technical Solution processes have a **“Strong” positive** relationship with Better Performance

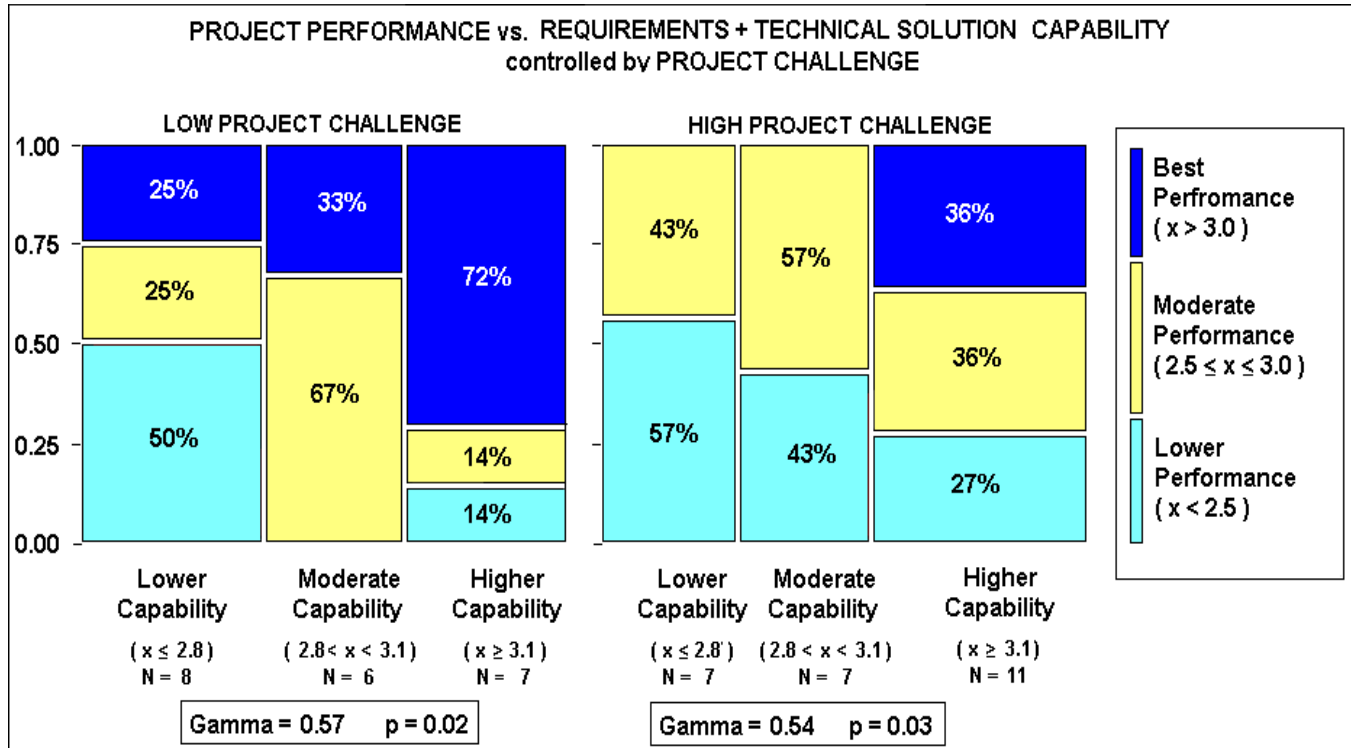




# Summary of Relationships



# Requirements + Technical Solution vs. Project Performance, controlled by Project Challenge



Project challenge factors:

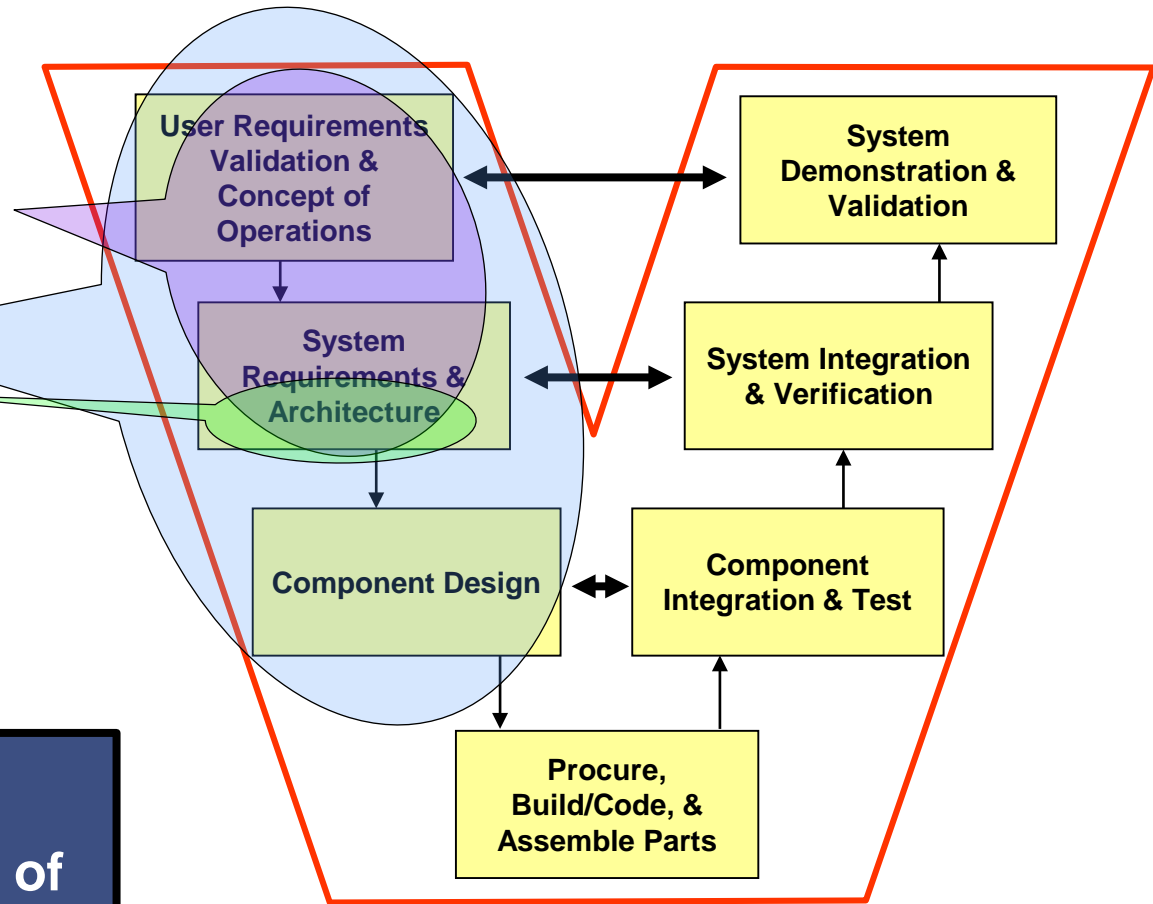
- Life cycle phases
- Project characteristics (e.g., size, effort, duration, volatility)
- Technical complexity
- Teaming relationships

Regardless of Project Challenge, better Requirements Dev't and Mg't and better Technical Solution processes shows a “Strong” **positive** relationship with Better Performance



# Mapping of Results to System Development

- Project Planning
- Project Monitoring & Control
- Risk Management
- Requirements Dev't & Mg't
- Technical Solution
  - Trade Studies
  - Product Architecture
- Product Integration
- Verification
- Validation
- Configuration Management
- IPT-Based Capability



[http://ax.losangeles.af.mil/se\\_revitalization/main.htm](http://ax.losangeles.af.mil/se_revitalization/main.htm)

**V-Model of System Development**

## Conclusion

The early phases of SE have the most impact



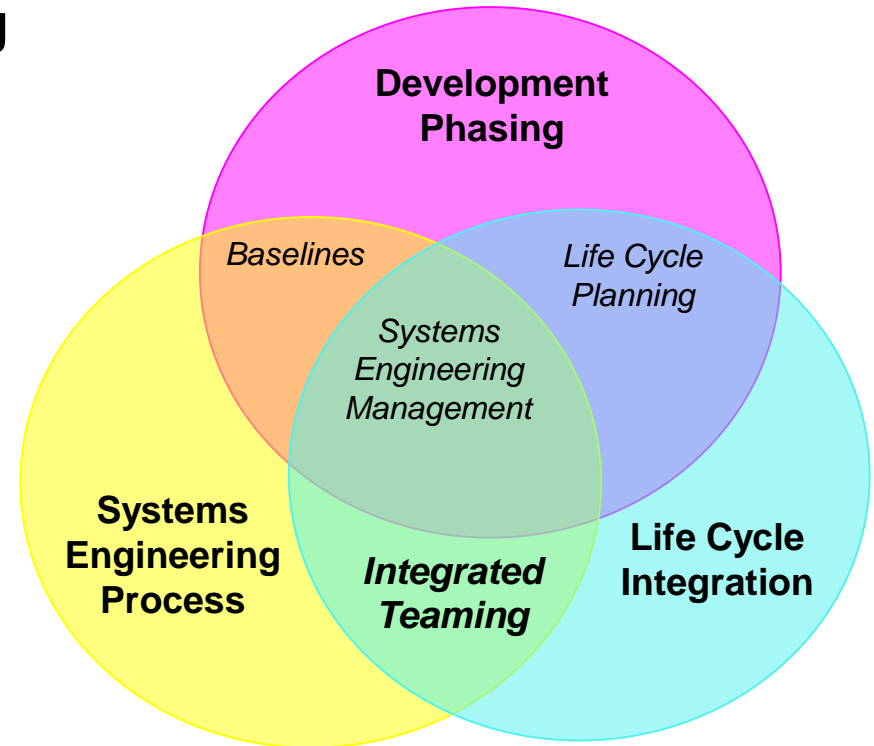
# Agenda

The Need for Systems Engineering

The NDIA Systems Engineering Effectiveness Study (SEES)

Survey Results

Using the Results



# Moving Forward

## What We Have Learned with the SEES ?

- **projects whose suppliers apply good SE practices perform better, regardless of size and difficulty**
- **SE best practices applied by suppliers early in a project have the greatest impact on project performance**
  - Requirements development and management
  - Architecture development
  - Trade Study performance
- **projects whose suppliers make effective use of IPTs perform better**

## What Can We Do With This Knowledge ?

- **Effective deployment of SE best practices demands coordinated action from both System Acquirers and System Developers**



# So, Why Don't Suppliers and Acquirers Do It?

## Supplier Issues

**Insufficient budget**

**Schedule driven projects**

- Need for immediate tangible results
- Fear of 'paralysis by analysis'

**Failure to understand value of SE**

- Absence of deliverable outputs from SE

**Lack of available SE staff**

**Lack of incentives**

- Lack of contractual requirements for SE
- No encouragement or reward
- Inattention to SE efforts and results

## Acquirer Issues

**Lack of Policy requiring SE?**

- No! Policy exists promoting the use of SE
  - USD/AT&L "Policy for Systems Engineering in DoD" of 20-Feb-2004
  - ASA(ALT) Memorandum, "Army Systems Engineering Policy" of 13-Jun-2005
  - SAF Memorandum, "Systems Engineering Plan (SEP) Requirements Memo" of 14-Mar-2007

**Lack of effective guidance for implementing effective SE?**

- Maybe. Guidance exists but much of it is difficult to operationalize
  - Defense Acquisition Guidebook

**Lack of understanding**

- Probably. Implementing effective SE is a very difficult task. Without both training and experience, it is difficult to know what to do.



# Suggestions for System Acquirers 1

## Ensure that suppliers provide effective SE

- **Include SE requirements in RFPs**
  - Evaluate bidder's SE Plan as part of the source selection criteria
  - Require evidence of SE performance through CDRLs
  - Require periodic self-assessment and reporting of SE performance
  - Require SE visibility in IMS, IMP, EVMS, etc.
  - Require independent assessment and reporting of SE performance at PDR, CDR, etc.
- **Stress SE performance in negotiations and contracting**
  - Mandate compliance with RFP requirements and bidder proposals for SE
  - Avoid compression / elimination of SE efforts to accommodate schedule
  - Include incentives for early and effective SE activities
- **Monitor SE performance during contract execution**
  - Provide timely and comprehensive review of SE deliverables
    - Insure sufficient program office staff and skills to do this
  - Participate in SE IPTs



# Suggestions for System Acquirers 2

## Ensure that the Program Office provides effective SE

- **Include sufficient SE expertise in the Program Office**
  - Hire trained and capable Systems Engineers
  - Provide SE training for Program Office staff
    - Develop on-line JIT training
  - Include SE staff in the Program Office decision making process
- **Set an example. Employ SE best practices for:**
  - Requirements Development and Management
  - Trade Studies
  - Architecture Development, Evaluation, and Management
  - Configuration Management
- **Discuss and stress the supplier's SE performance in ALL reviews with the contractors. Let them know you're watching!**
- **Collect and analyze data from all programs to improve understanding of the effectiveness of specific SE activities.**





# Suggestions for System Suppliers

**Define, develop, deploy, monitor, and enforce SE processes for ALL projects throughout the organization**

**Ensure SE competency within the organization**

- Build or maintain a cadre of skilled System Engineers
- Provide SE training for both Systems Engineers and project Managers

**Ensure SE integration within the organization**

- Clearly define SE roles, responsibilities, and authorities

**Identify and adopt SE assessment methods**

- Identify, evaluate, and adopt SE assessment methods
- Train internal staff in assessment processes



# SE Effectiveness

## *Points of Contact*



Al Brown	<a href="mailto:alan.r.brown2@boeing.com">alan.r.brown2@boeing.com</a>
Geoff Draper	<a href="mailto:gdraper@harris.com">gdraper@harris.com</a>
Joe Elm	<a href="mailto:jelm@sei.cmu.edu">jelm@sei.cmu.edu</a>
Dennis Goldenson	<a href="mailto:dg@sei.cmu.edu">dg@sei.cmu.edu</a>
Al Mink	<a href="mailto:Al_Mink@SRA.com">Al_Mink@SRA.com</a>
Ken Ptack	<a href="mailto:ken.ptack@incose.org">ken.ptack@incose.org</a>
Bob Rassa	<a href="mailto:RCRassa@raytheon.com">RCRassa@raytheon.com</a>
Mike Uchino	<a href="mailto:michael.uchino@afit.edu">michael.uchino@afit.edu</a>

The report, “A Survey of Systems Engineering Effectiveness” is available at:  
<http://www.sei.cmu.edu/publications/documents/08.reports/08sr034.html4.html>





# BACKUP



# Acknowledgements

## Primary Contributors

Alan R. Brown	Robert Bruff	Brian Donahue	Nicole Donatelli	Geoffrey Draper	Terry Doran
Khaled El Emam	Joseph Elm	Dennis Goldenson	Sherwin Jacobson	Al Mink	Angelica Neisa
Gordon F. Neary	Brad Nelson	Ken Ptack	Mike Uchino		

## Supporters

Robert Ferguson	Mike Konrad	Brian Gallagher	Keith Kost	James McCurley
Tom Merendino	Gerald Miller	Mike Phillips	Dave Zubrow	Larry Farrell

## NDIA SE Effectiveness Committee Members

Dennis Ahearn	Col. Warren Anderson	Marvin Anthony	Ben Badami	David P. Ball
Alan R. Brown	Al Bruns	Robert Bruff	Thomas Christian	John Colombi
Jack Crowley	Greg DiBenedetto	Jim Dietz	Brian Donahue	Terry Doran
Geoffrey Draper	Joseph Elm	Jefferey Forbes	John P. Gaddie	Donald J. Gantzer
Dennis Goldenson	Dennis E. Hecht	Ellis Hitt	James Holton	Eric Honour
Sherwin Jacobson	George Kailiwai	Ed Kunay	Dona M. Lee	Jeff Loren
David Mays	John Miller	Al Mink	Gordon F. Neary	Brad Nelson
Rick Neupert	Odis Nicoles	Brooks Nolan	Ken Ptack	Michael Persson
Arthur Pyster	Bob Rassa	James "Rusty" Rentsch	Paul Robitaille	Garry Roedler
Rex Sallade	J. R. Schrand	Sarah Sheard	Jack Stockdale	Jason Stripinis
Mike Uchino	Ruth Wuenschel	Brenda Zetervall		

# FAQs <sub>1</sub>

**Q1: What do you mean by ‘*the least SE*’ and ‘*the most SE*’?**

A1: It’s all relative. Our survey scored each project’s SE performance by assessing artifacts resulting from SE activities such as Requirements Development and Management, Trade Studies, System Architecture Development, Interface (External and Internal) Management, and many more. Based on these scores, the projects were binned into categories of *Higher, Intermediate, or Lower SE* capability.

**Q2: ...and what is ‘Best Performance’?**

A2: Again, it’s a relative measure of project performance. Our survey scored each project’s performance by assessing it’s conformance to budget and schedule, and it’s satisfaction of requirements. Based on these scores, the projects were binned into categories of *Best, Moderate, or Lower Project Performance*.

**Q3: So what does it mean?**

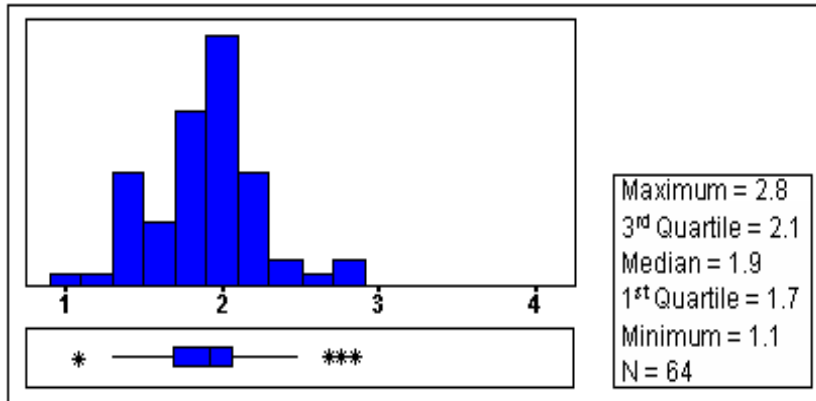
A3: Projects that do a better job of Systems Engineering perform better (closer to budget, closer to schedule, and meet more requirements) than projects that do a poorer job of Systems Engineering

# FAQs <sub>2</sub>

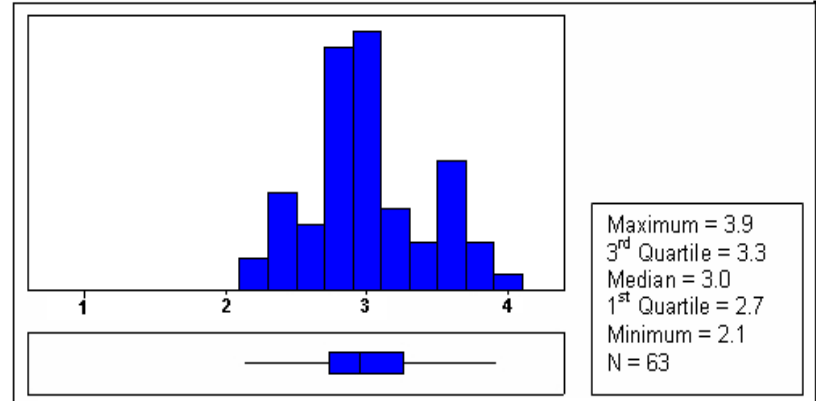
**Q3: How do you know that SE was responsible for the better performance?**

A3: We also collected and analyzed data for other factors that could impact project performance – things like Project Challenge, Project Environment, and Acquirer capability, looking for their relationships to project performance. Among the things that we found was the that good SE helps projects regardless of how challenging they are

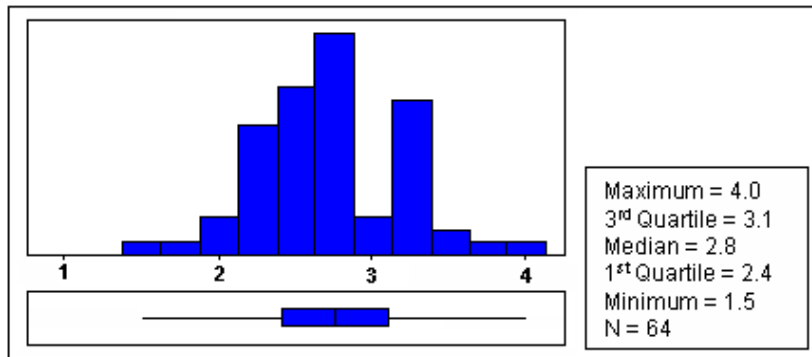
# Overview of Projects Surveyed



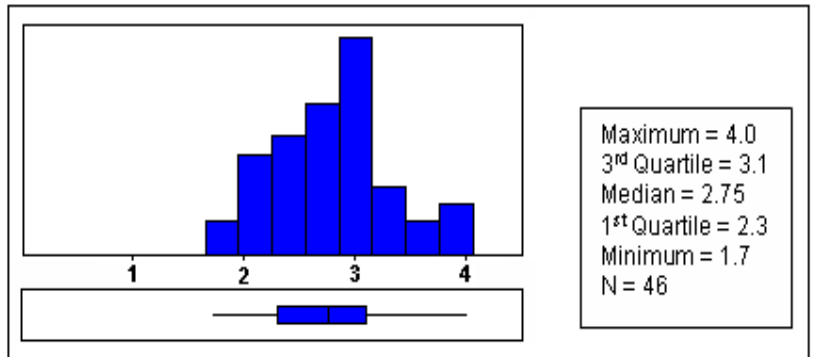
**Project Challenge (PC)**



**Overall SE Capability (SEC)**



**Acquirer Capability (AC)**



**Project Performance (Perf)**

**Sufficient variation to support analysis**

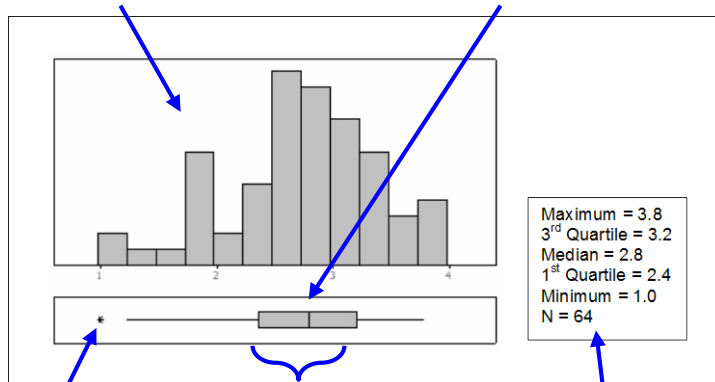
# Analysis

Calculate 'scores' for each variable (e.g., Perf , PC, AC, SEC, SEC<sub>PP</sub>, SEC<sub>PMC</sub>, SEC<sub>RSKM</sub>)

Analyze variable distributions to ensure sufficient variation for analysis

Analyze relationships between variables

Histogram of response frequencies

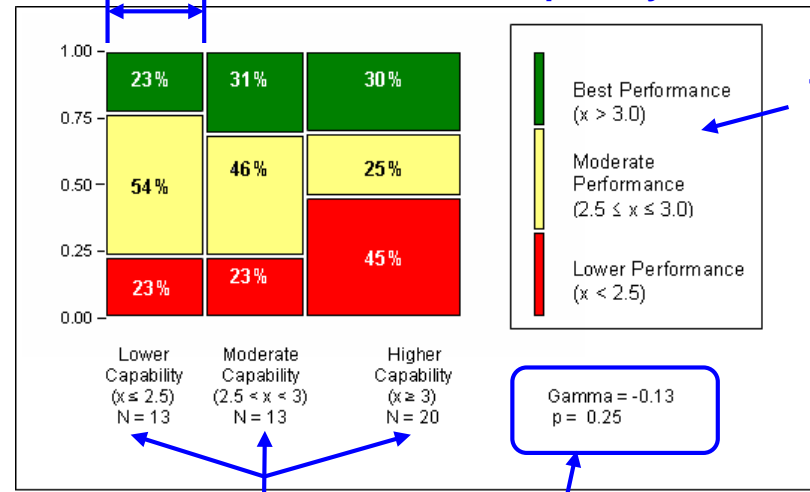


Outliers

Interquartile Range

Data statistics

Column width denotes % of projects with this level of capability



Total sample performance distribution

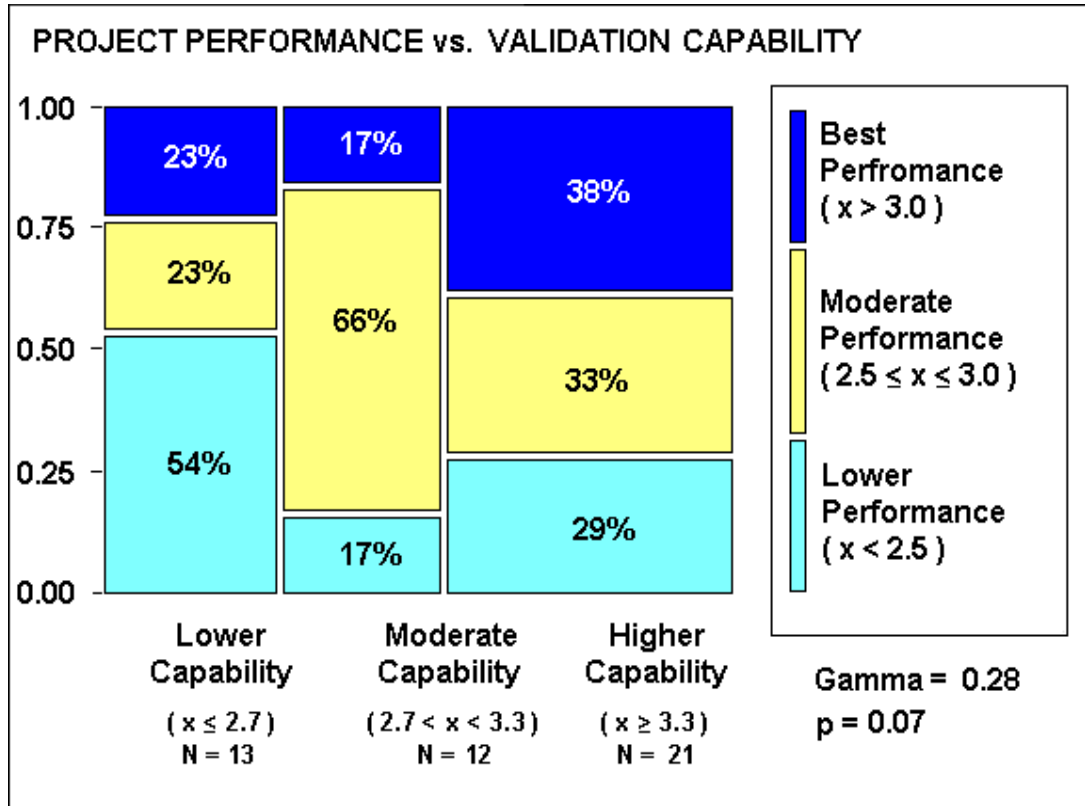
Projects exhibiting a given level of relative capability

Measures of association & statistical test

$\Gamma$  = strength of relationship  
p = chance probability



# Validation vs. Project Performance

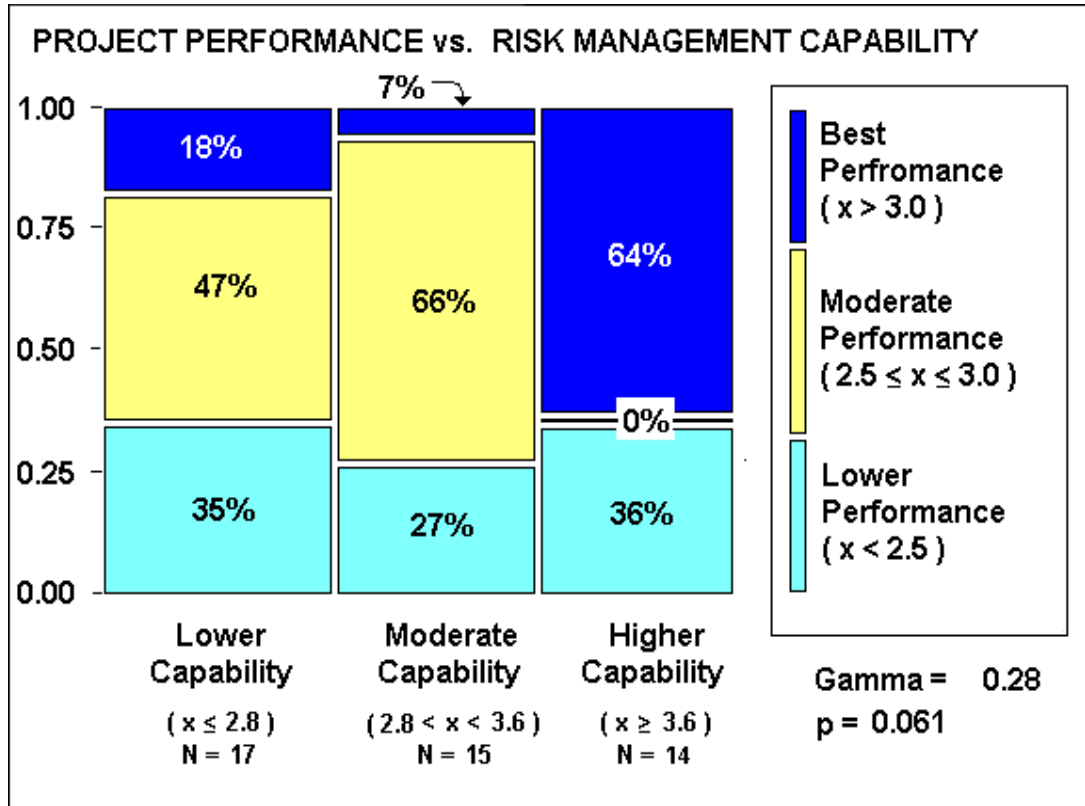


## Validation assessment examined

- Validation Procedures
- Documented Acceptance Criteria
- List of items under Configuration Management

Better Validation capabilities have a “Moderately Strong” **positive** relationship with Better Performance

# Risk Management vs. Project Performance

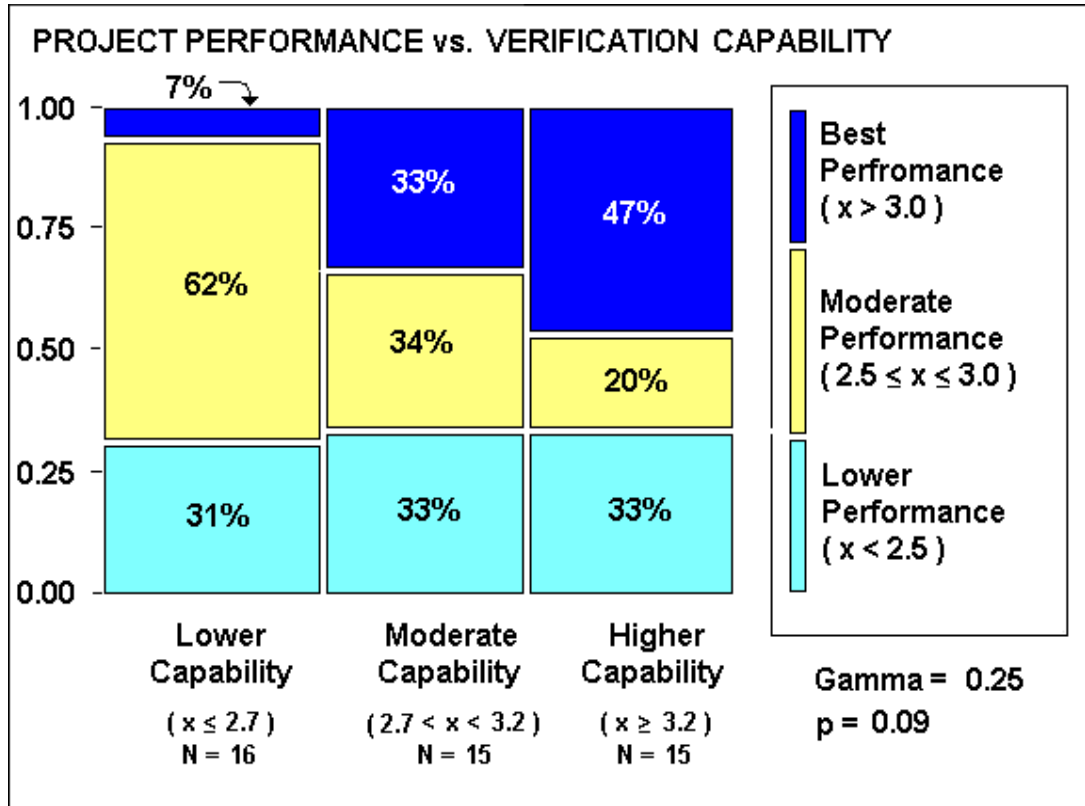


## Risk Management assessment examined

- List of Risks
- Risk Mitigation Plans
- Monitoring and Reporting of Risks and Mitigation Plans
- Integration with Project Decision Making
- Integration with IMS

Better Risk Management has a “Moderately Strong” **positive** relationship with Better Performance

# Verification vs. Project Performance

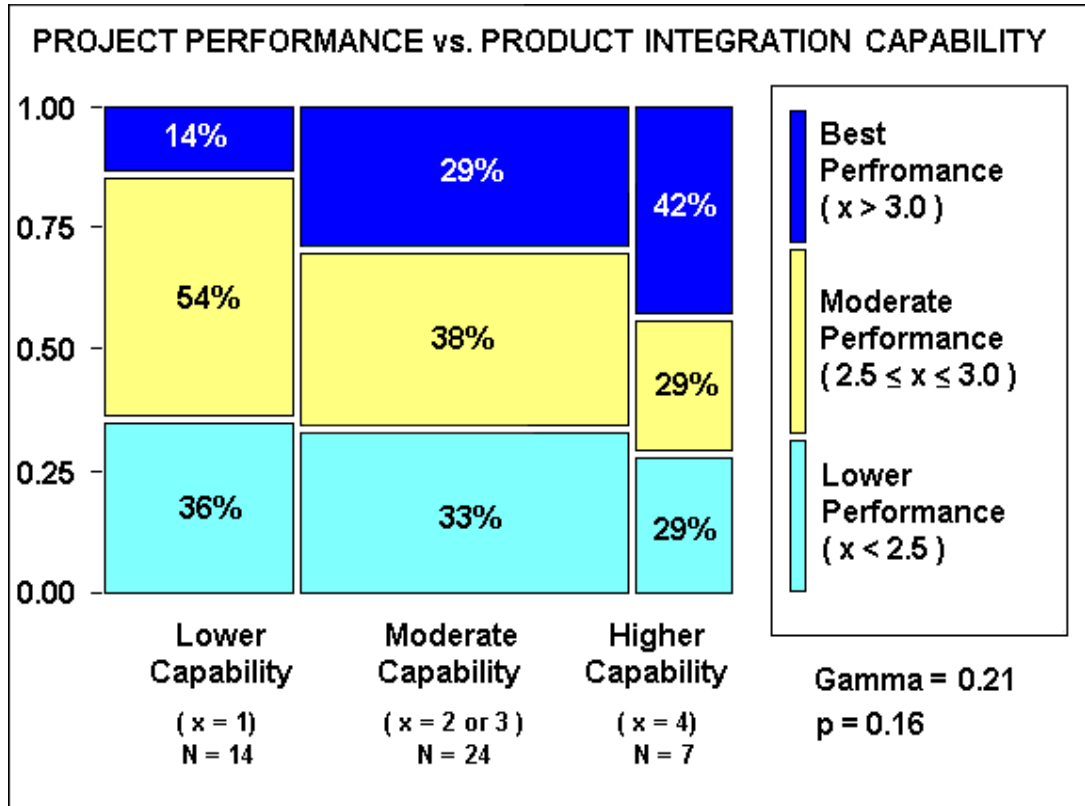


## Verification assessment examined

- Verification Procedures
- Documented Acceptance Criteria
- Documented Technical Review Process
- Documented non-advocate reviews

Better Verification capabilities have a “Moderately Strong” **positive** relationship with Better Performance

# Product Integration vs. Project Performance

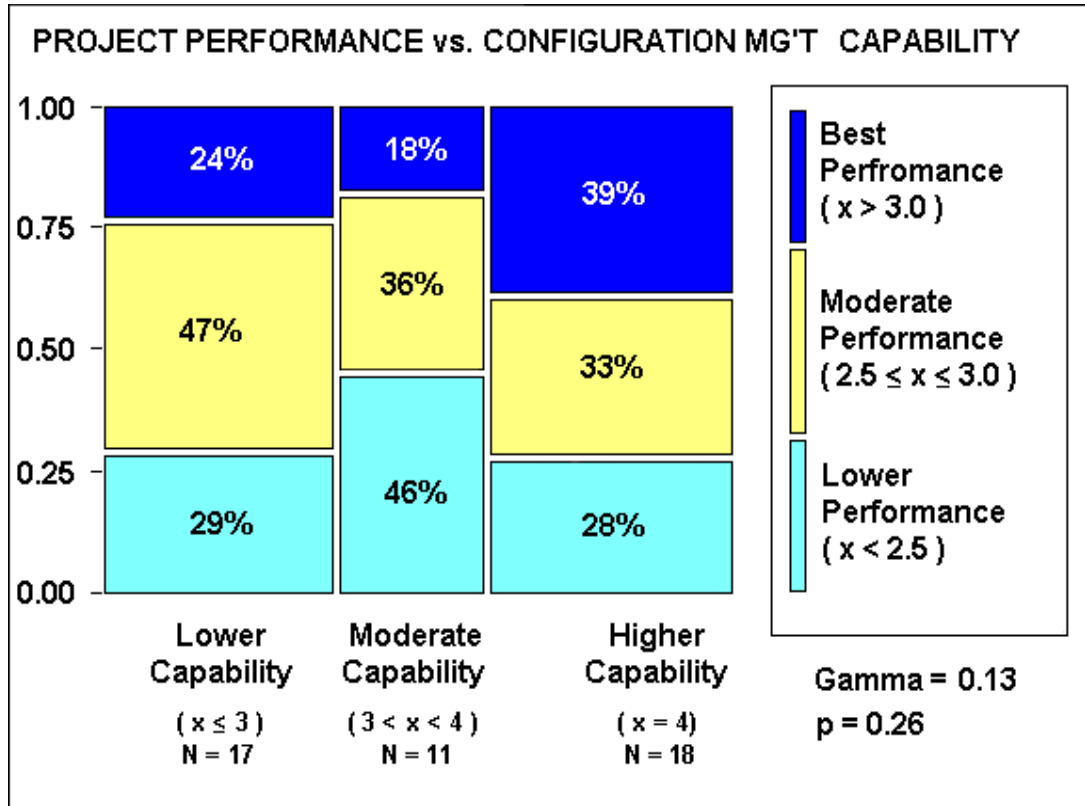


## Product Integration assessment examined

- Documented Integration Process
- Documented Integration Criteria

Better Product Integration capabilities have a “Weak” **positive** relationship with Better Performance

# Configuration Mg't vs. Project Performance

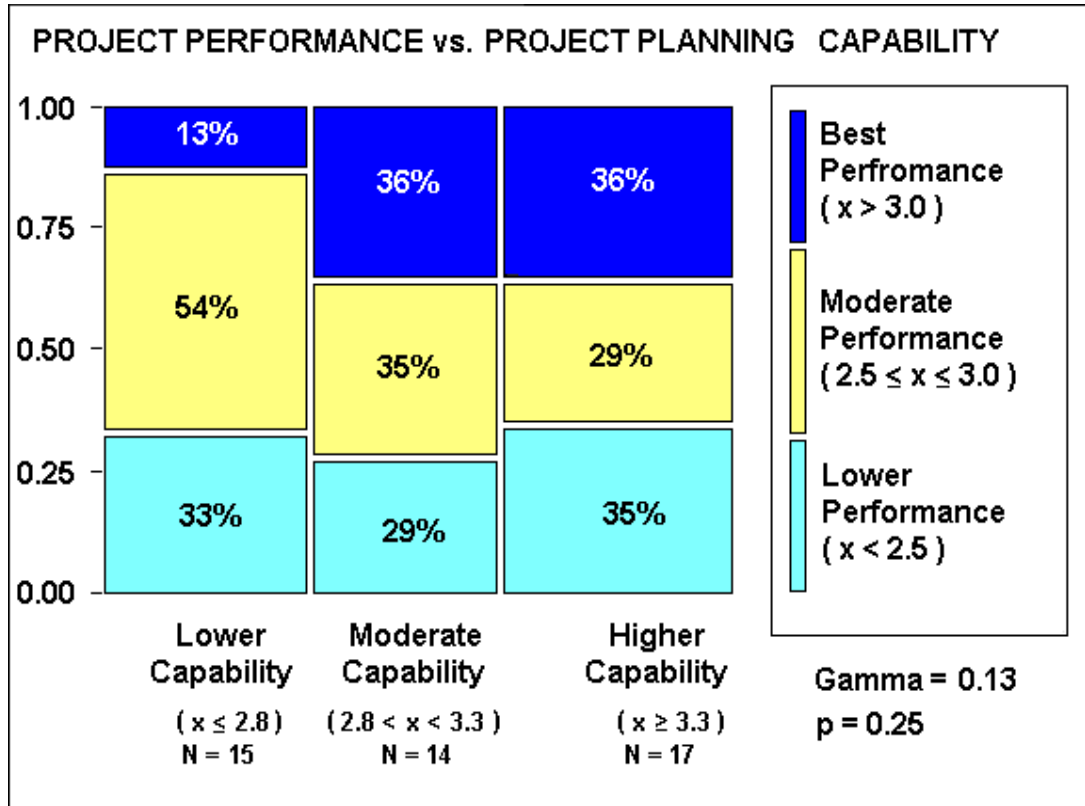


## Product Integration assessment examined

- Change Control Board Charter
- Records of requested and implemented changes
- Configuration Baselines

Better Configuration Management capabilities have a “Weak” **positive** relationship with Better Performance

# Project Planning vs. Project Performance

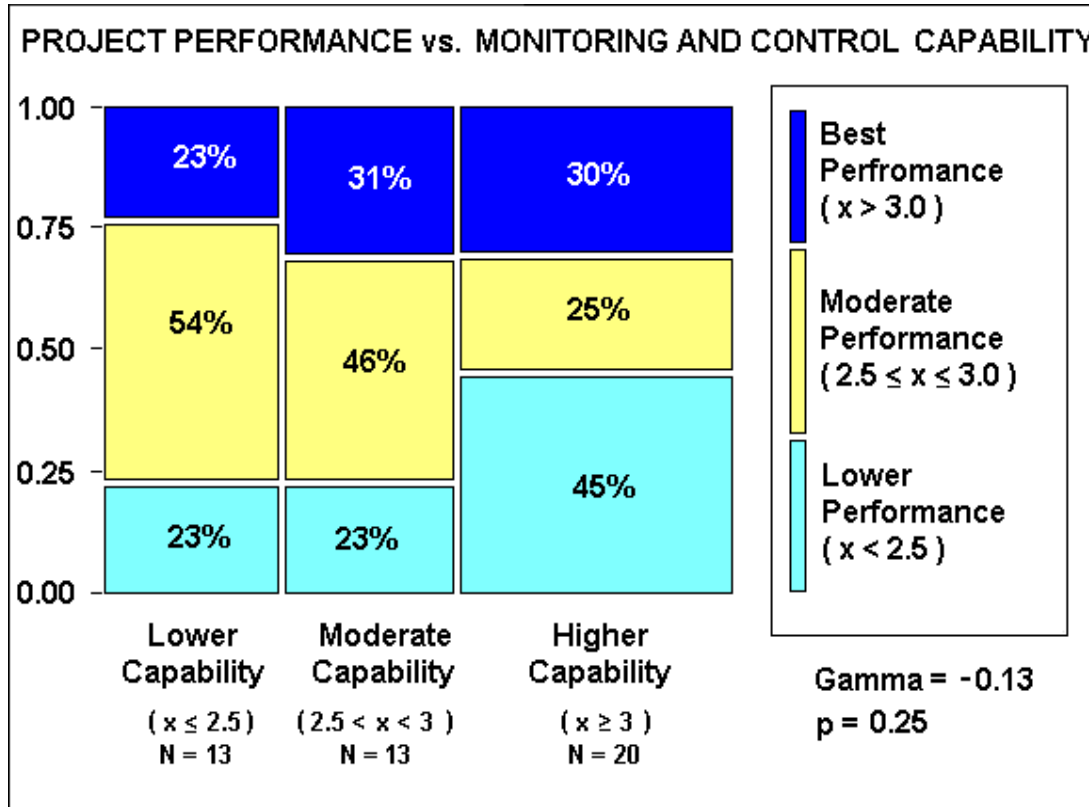


## Project Planning assessment examined

- Project Planning Processes
- Work Breakdown Structure
- Technical Approach
- IMP and IMS
- Plan for technical reviews
- Systems Engineering Plan

Better Project Planning capabilities have a “Weak” **positive** relationship with Better Performance

# Project Monitoring vs. Control and Project Performance

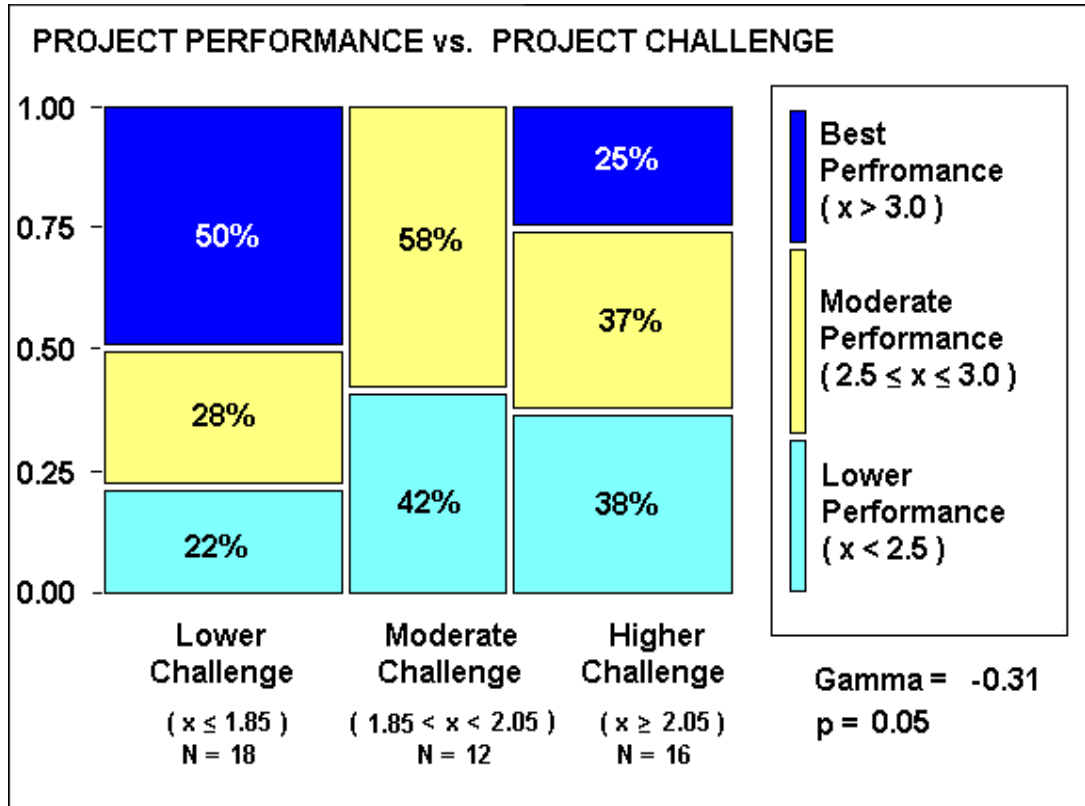


## Project Planning assessment examined

- SE Costing and Tracking
- Cost and Schedule Baselines
- EVMS Data
- EVMS Data from Suppliers
- Defined Thresholds for SPI and CPI variance

Better Project Monitoring and Control capabilities have a “Weak” **negative** relationship with Better Performance

# Project Challenge vs. Project Performance



## Project challenge factors:

- # of Life cycle phases
- Project characteristics (e.g., size, effort, duration, volatility)
- Technical complexity
- Teaming relationships

More Challenging Projects do not perform as well.



# Relating Project Performance to Project Challenge and SE Capability

