The Effectiveness of Systems Engineering:

On Federal System Development Programs

First Public Release

Of Major New NDIA Study by
The Systems Engineering Effectiveness Committee
(SEEC)

Al Mink
SEEC Member
& SRA International
October 2007

SE Effectiveness
Overview

The SE Effectiveness Survey

Quantifies the relationship between the application of Systems Engineering best practices and the performance of system development projects

Projects with better Systems Engineering capabilities deliver better Project Performance!

TODAY'S OUTLINE

1. **The Challenge**
2. **The Rigor**
3. **The Results!**
4. **Conclusions & Caveats**

The Challenge
Stakeholder Analysis

Those interested in such a study – and their interests

Customers
- DoD #1 SE Issue – "Inconsistent SE Practices across life cycle"
- Validate initiatives to revitalize SE
- Increase emphasis of SE content in RFPs and Proposals

Industry (System Developers & Integrators)
- Proposal may skimp on SE; Budget pressures on SE

Associations & Academia
- Unable to fully satisfy their members and students

SE professionals
- Lack rigorous justification for their recommendations

The Challenge

Previous Studies – Partial Insights

Gruhl, National Avionics and Space Administration (NASA), 1992

Compared upfront expenditures to eventual cost growth

Herbsleb, Software Engineering Institute (SEI), 1994

Studied ROI on process improvement in software

Honour, International Council on Systems Engineering (INCOSE), 2002

Surveyed industry to compare SE Effort to cost & schedule

Valerdi & Boehm, Constructive System Engineering Cost Model (COSYSMO), 2004

Developed parametric estimation model similar to COCOMO

Boehm & Valerdi, SE ROI (COCOMO), 2006

Analyzed SE activities from COCOMO II

Others…

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION
STRENGTH THROUGH INDUSTRY & TECHNOLOGY

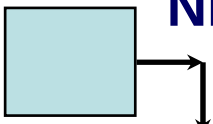
The Challenge

Previous Studies – Summary

STUDY		APPLICABILITY		
Author & Background	**Findings**	**SE Activities**	**Definition of Success**	**Characteristics of Project**
Gruhl (1992) 32 NASA Pgms	8-15% Upfront Best	First two of five development phases	Cost (Less cost overrun)	Large; Complex; all NASA
Herbsleb (1994) 13 CMM Companies	Process Improvement ROI 4.0 – 8.8	CMM Process Areas	Cost (Cost reduction through SE investment)	Various; federal contracting
Honour (2004) Survey INCOSE SEs	15-20% of project should be SE	Overall SE level of effort (Cost) & related SE quality	Cost & Schedule	Various sizes (measured by total project cost)
Boehm & Valerdi (2006) COCOMO II	SE importance grows with project size	COCOMO II RESL (Architecture and Risk)	Cost	Various sizes, but software systems only
Boehm & Valerdi (2004) COSYSMO	Estimate within 30% effort 50% - 70% of time	33 activities defined by EIA 632	Cost	Mostly successful projects from federal contractors
Ancona & Caldwell (1990) Boundary Management	Managing team boundary 15%; more is better	Team boundary activities – interface between team and external	Product Performance (Successfully marketed products)	Technology products
Frantz (1995) Boeing side-by-side projects	More SE yielded better quality & shorter duration	Defined by Frantz	Product Performance & Schedule (Quality of product and duration of project)	Three similar systems for manipulating airframes during assembly

Mink, 2007

The Rigor
Followed Planned Lifecycle



Form Team — **NDIA SEEC**

Develop Approach — **Survey (Industry Projects)**

Validate Approach — **Pilot Study of Survey**

Collect Data — **Anonymous via Web**

Analyze Data — **46+ Projects, by SEI**

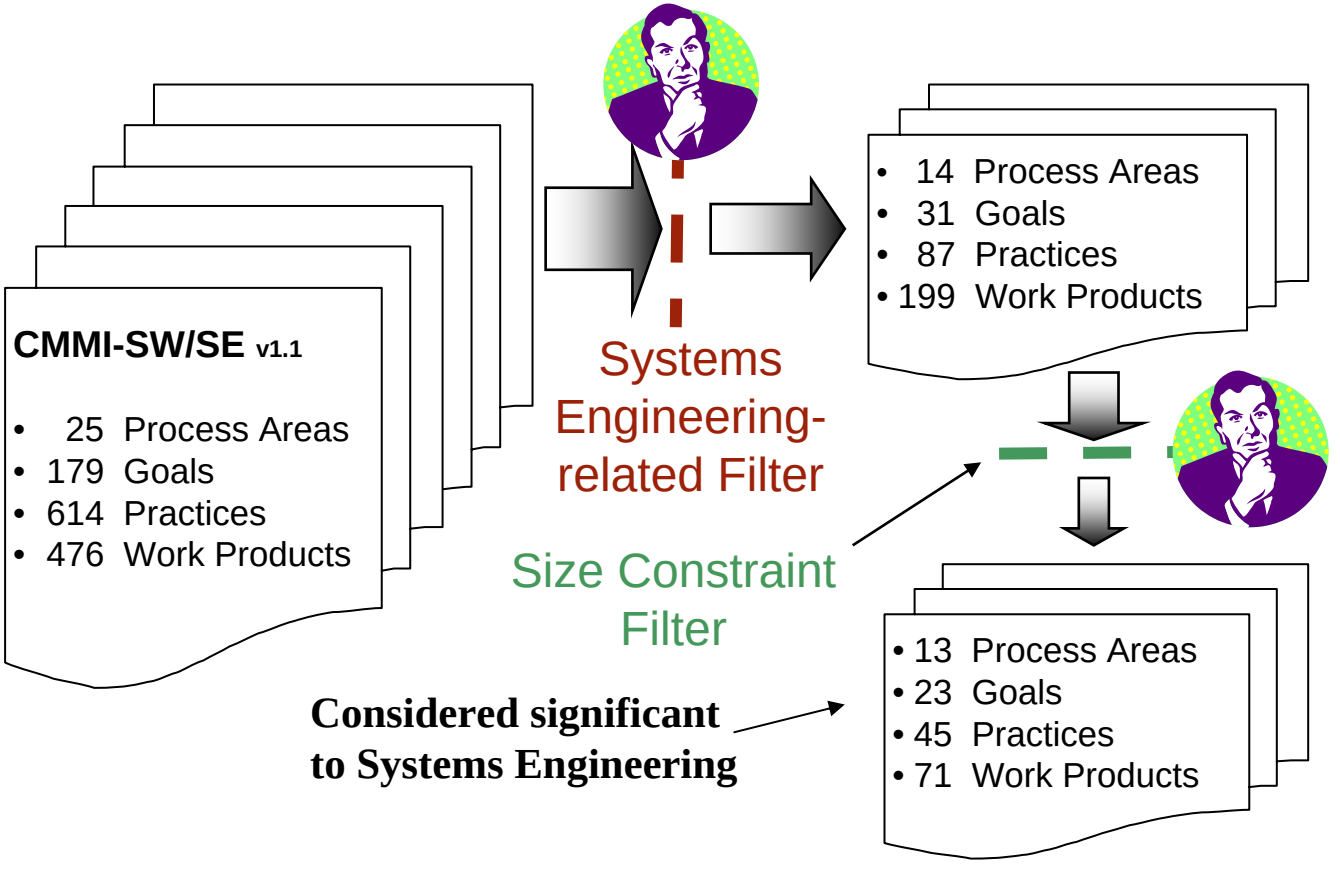
Publish Results — **Two Reports:**

1. ***Public Report***
2. ***Restricted Attachment***

This study spanned three years

The Rigor

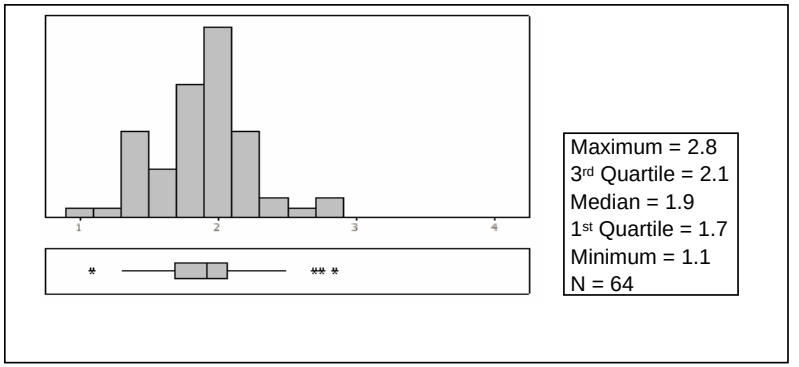
Formally Selected Set of SE Activities

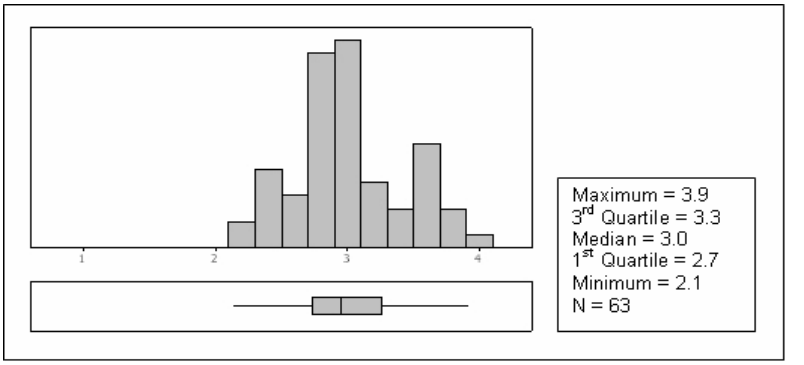


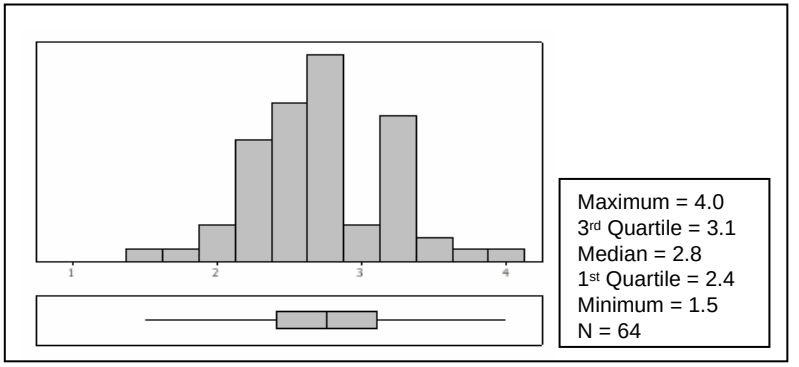
Survey was developed based on standards and recognized SE experts

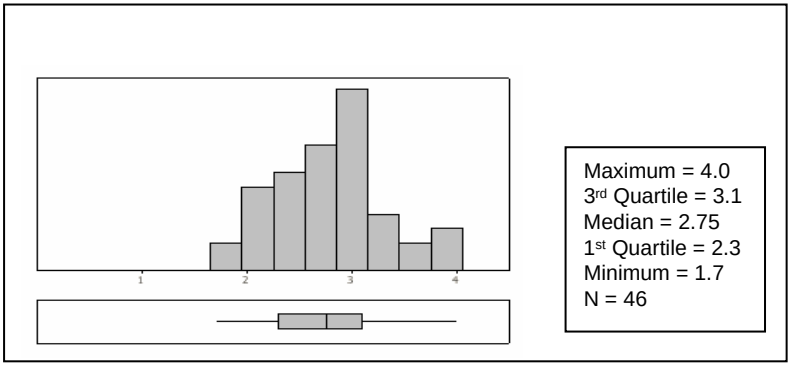
The Rigor

Validated Survey Responses





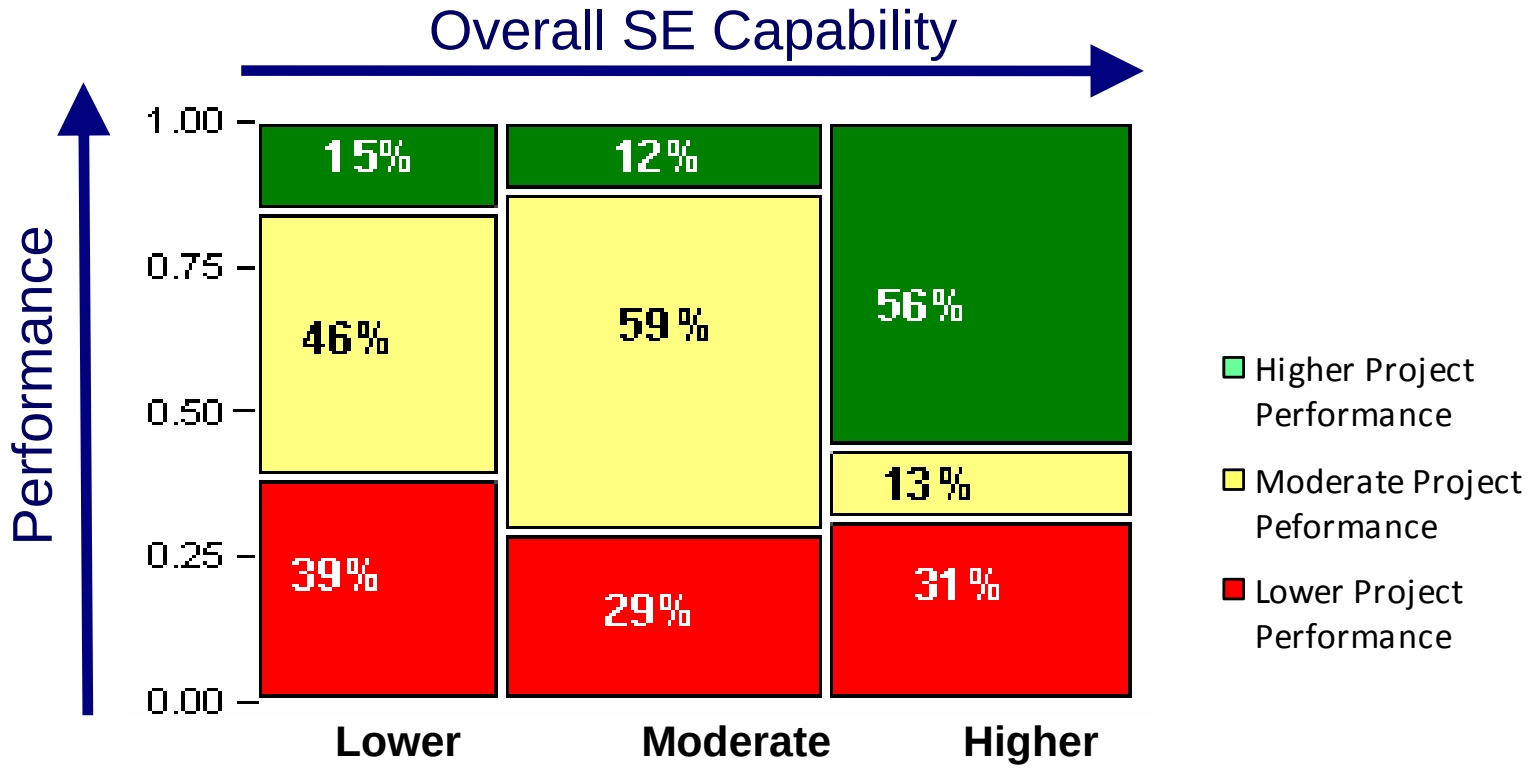




Analyzed distributions, variability, relationships…
To ensure statistical rigor and relevance

Results

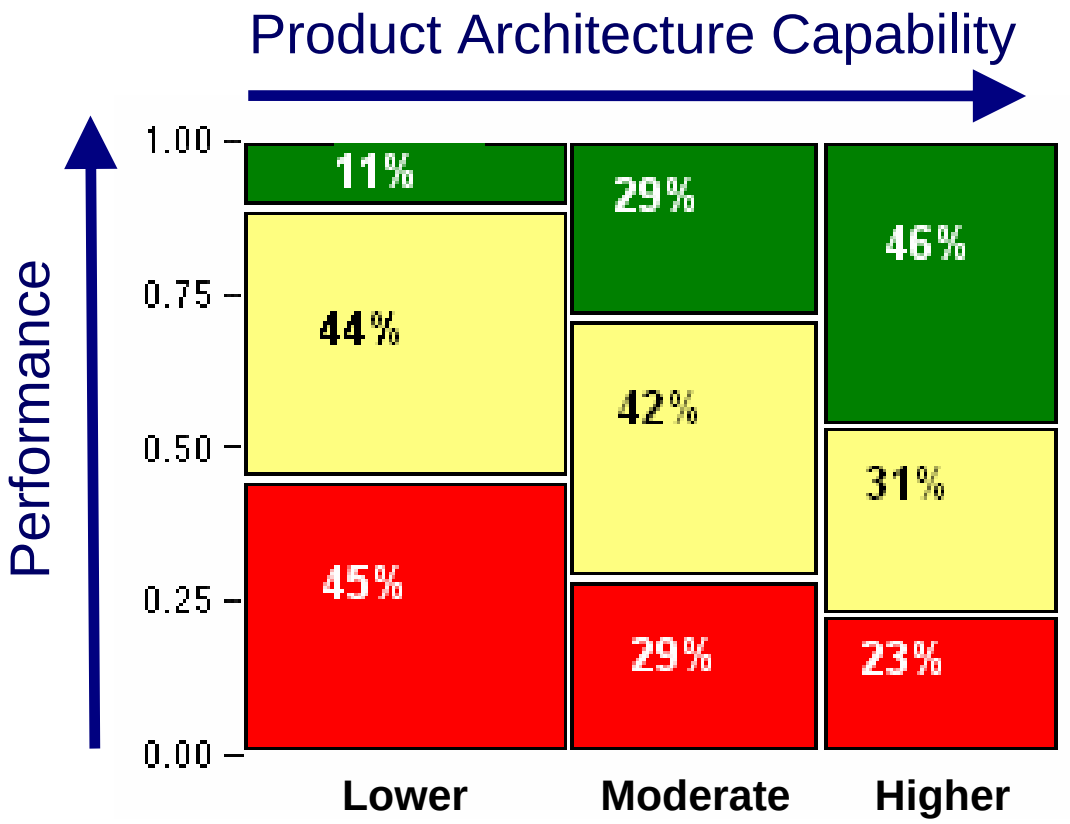
Overall SE Capability & Project Performance



Projects with better <u>Overall Systems Engineering Capability</u> delivers better Project Performance *(cost, schedule and scope)*

Results

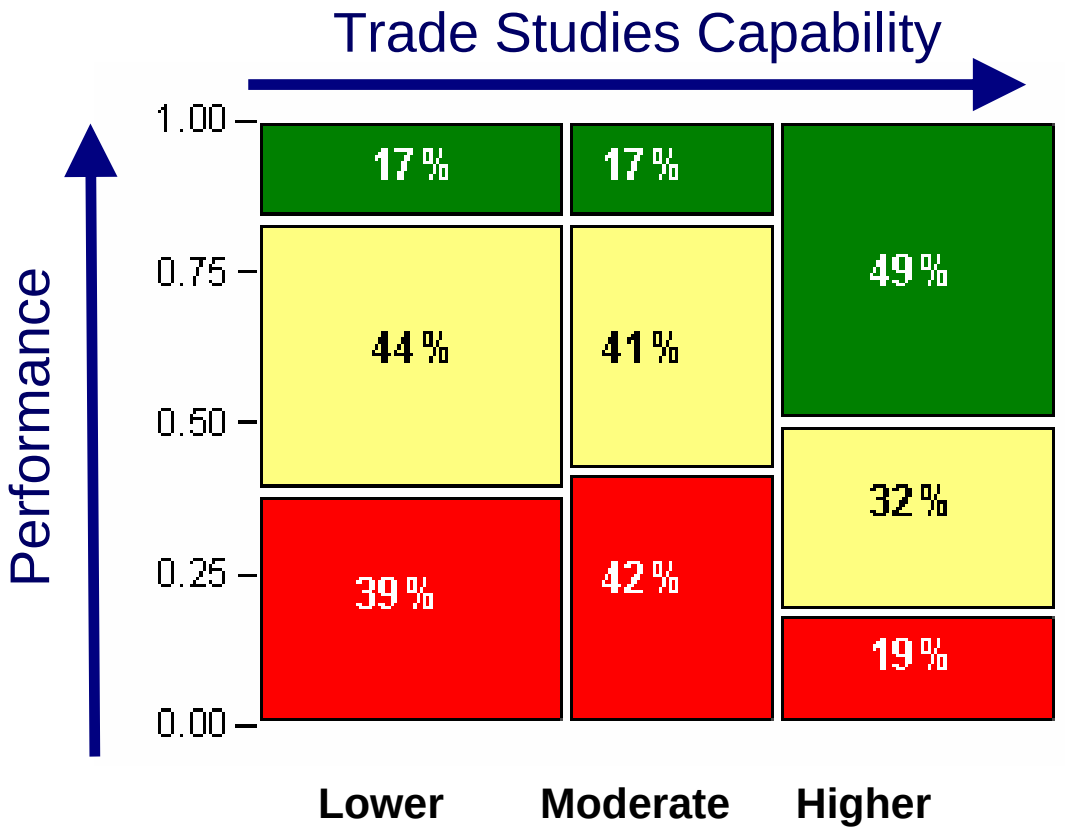
1. Product Architecture and Project Performance



Projects with better <u>Product Architecture</u> Capability Show a "<u>Moderately Strong / Strong" Positive Relationship</u> with Performance

Results

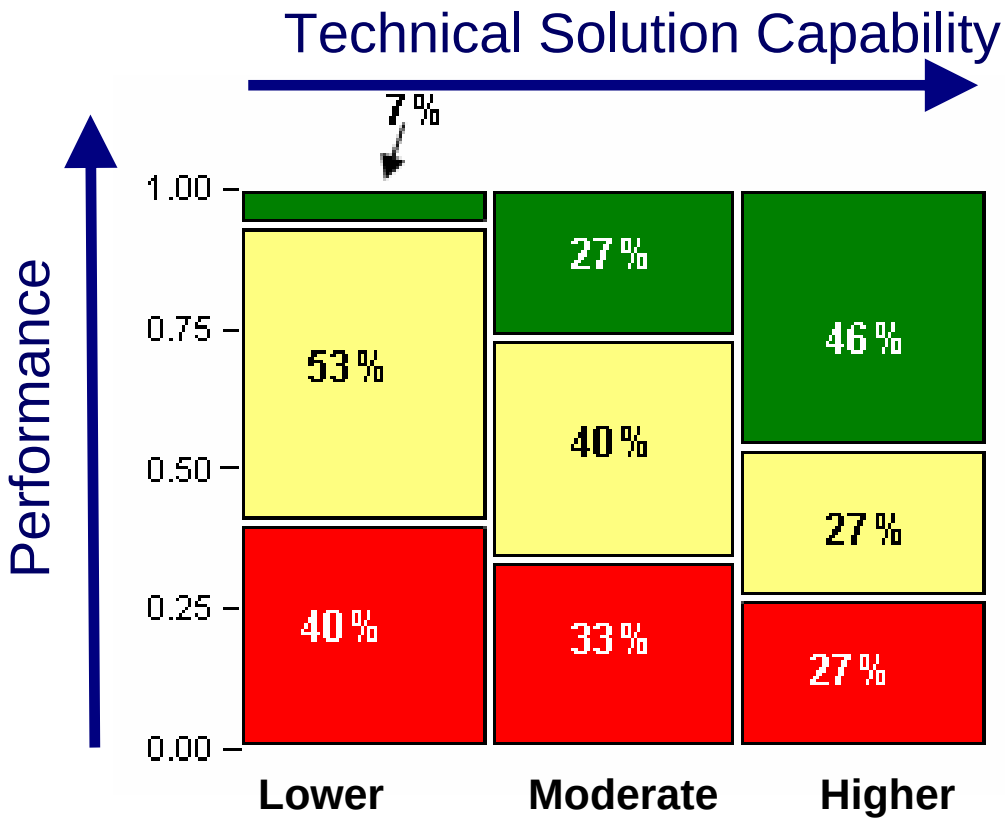
2. Trade Studies and Project Performance



Projects with better Trade Studies Capability Show a "Moderately Strong / Strong" Positive Relationship with Performance

Results

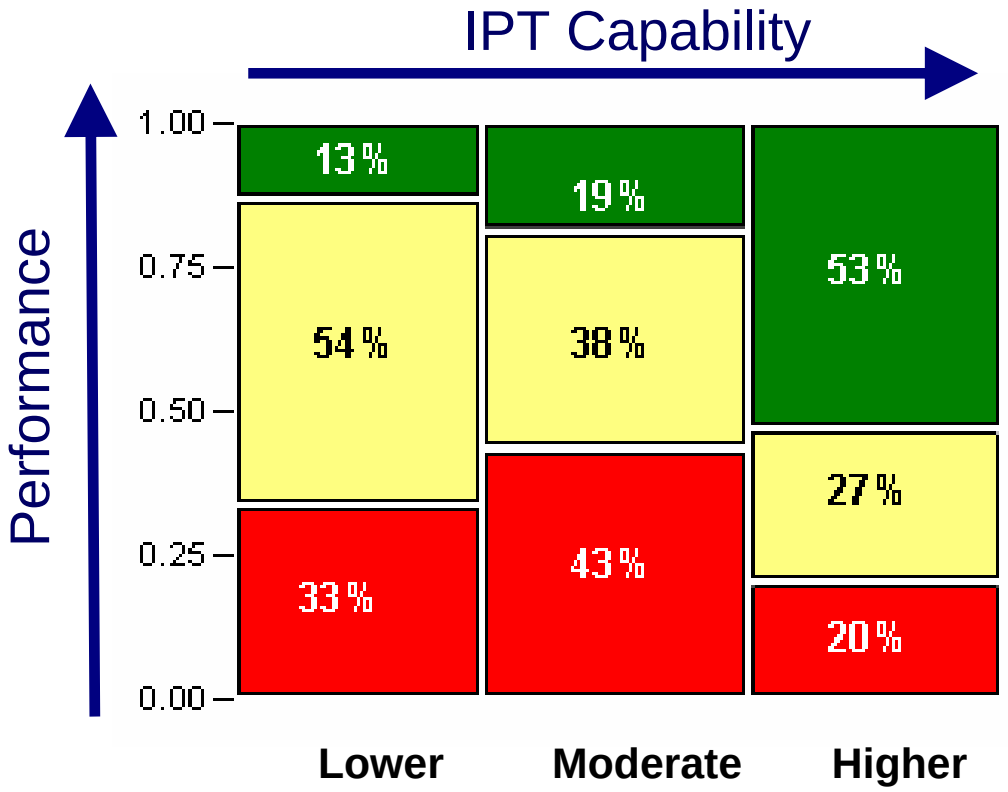
3. Technical Solution and Project Performance



Projects with better Technical Solution Capability Show a "Moderately Strong / Strong" Positive Relationship with Performance

Results

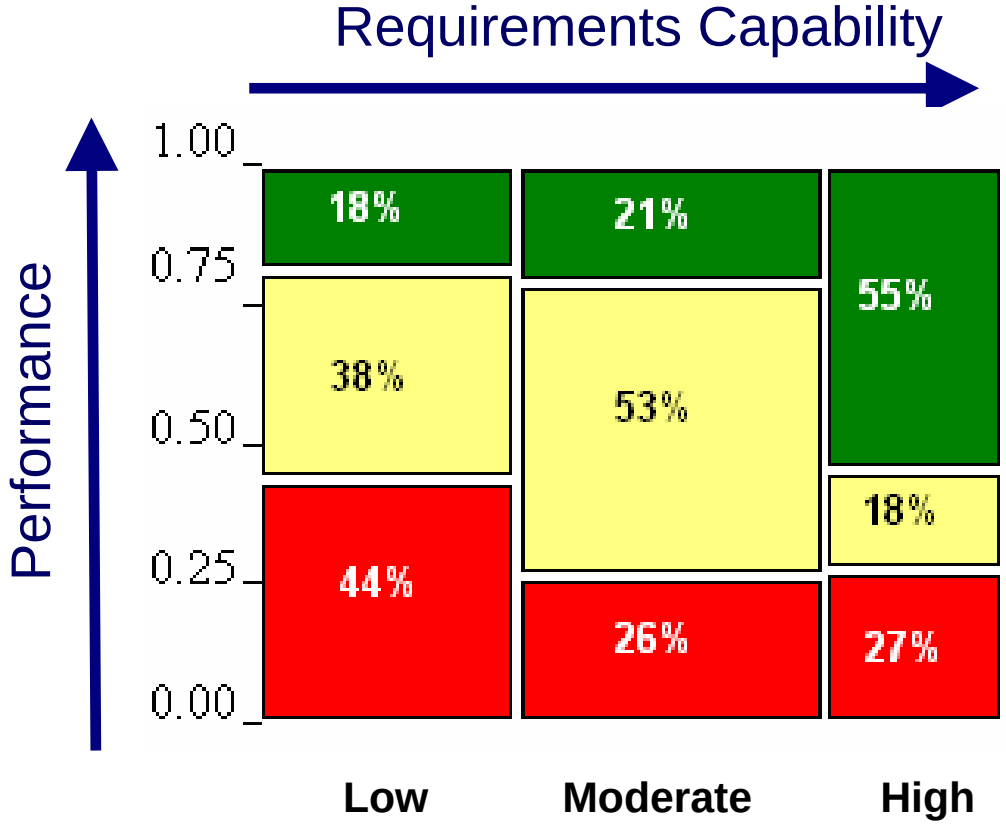
4. IPTs and Project Performance



Projects with better IPTs Capability
Show a "Moderately Strong / Strong" Positive Relationship with Performance

Results

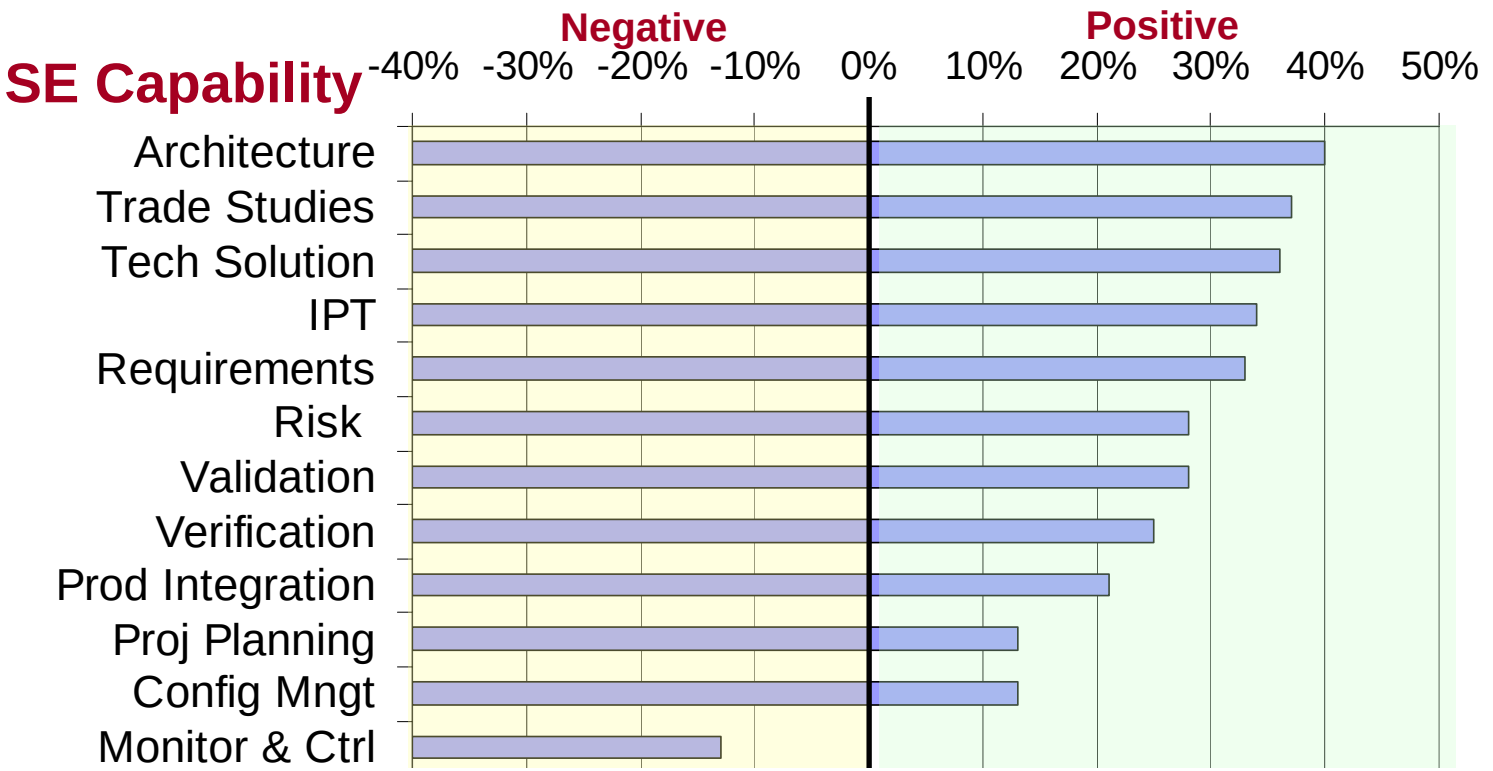
5. Requirements and Project Performance



Projects with better Requirements Management and Development Capability Show a "Moderately Strong / Strong" Positive Relationship with Performance

Results

Summary of Relationships



Relationship to Performance (Gamma)

Conclusions & Caveats

Summary

SE Effectiveness

- Provides credible measured evidence about the value of disciplined Systems Engineering
- Affects success of systems-development projects

Specific Systems Engineering Best Practices

- Highest relationships to activities on the “left side of SE Vee”

Environment (Project Challenge) affects performance too

- Some projects are more challenging than others ... and higher challenge affects performance negatively
- Yet good SE practices remain crucial for both high and low challenge projects

Conclusions & Caveats

Next Steps

- **Correlate Report Findings with Other Sources**
- **Develop Improvement Recommendations**
  - Policy, guidance, training, measures, reviews
- **Conduct Additional Analysis of Collected Data**
  - IV & V
  - Discover other relationships and correlations
- **Repeat the Survey to Gauge Improvements**
- **Survey Acquirers**

Acknowledgements

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SE Effectiveness

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Backup

NDIA SE Effectiveness Survey Analysis Slides

Reference: “A Survey of Systems Engineering Effectiveness”, Software Engineering Institute, Carnegie Mellon University, CMU/SEI-2007-SR-008. Joseph P. Elm, Dennis R. Goldenson, Khaled El Emam, Nicole Donatelli, Angelica Nissa.

Conclusions & Caveats

Consistent with "Top 10 Reasons Projects Fail"*

1. **Lack of user involvement**
2. **Changing requirements**
3. **Inadequate Specifications**
4. **Unrealistic project estimates**
5. **Poor project management**
6. **Management change control**
7. **Inexperienced personnel**
8. **Expectations not properly set**
9. **Subcontractor failure**
10. **Poor architectural design**

Above Items Can Cause Overall Program Cost and Schedule to Overrun

*** Project Management Institute**

Matching items noted in RED

Conclusions & Caveats

Consistent with "Top 5 SE Issues" (2006)*

- Key **systems engineering practices** known to be effective are **not consistently applied** across all phases of the program life cycle.

- **Insufficient systems engineering is applied early** in the program life cycle, compromising the foundation for initial requirements and architecture development.

- **Requirements are not always well-managed**, including the effective translation **from capabilities statements** into executable requirements to achieve successful acquisition programs.

- The quantity and quality of **systems engineering expertise is insufficient** to meet the demands of the government and the defense industry.

- Collaborative environments, including **SE tools, are inadequate** to effectively execute SE at the joint capability, system of systems, and system levels.

* OUSD AT&L Summit

Matching items noted in **RED**

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Summary SE Relationships to Project Performance

Details

			Relative Project Performance														
			Lower					Moderate					Higher				
	Gamma	p	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
Project Challenge																	
PC	-31%	5.0%	1.0	22%	28%	50%	1.85	1.85	42%	58%	0%	2.05	2.05	38%	38%	25%	4.0
Project Environment																	
CMMI	22%	13.0%	1.0	36%	57%	7%	1.95	1.95	29%	36%	35%	2.7	2.7	33%	28%	39%	4.0
IMP	5%	39.0%	1.0	25%	55%	20%	2.17	2.17	42%	29%	29%	2.84	2.84	33%	25%	42%	4.0
EXP	9%	33.0%	1.0	29%	42%	29%	2.5	2.5	39%	44%	17%	3.5	3.5	29%	29%	42%	4.0
Systems Engineering Capability																	
IPT	34%	4.0%	1.0	33%	54%	13%	2.5	2.5	43%	38%	19%	3.1	3.1	20%	27%	53%	4.0
PP	13%	25.0%	1.0	33%	54%	13%	2.8	2.8	29%	35%	36%	3.3	3.3	35%	29%	36%	4.0
PMC	-13%	25.0%	1.0	23%	54%	23%	2.5	2.5	23%	46%	31%	3.0	3.0	45%	25%	30%	4.0
RSKM	28%	6.1%	1.0	35%	47%	18%	2.8	2.8	27%	66%	7%	3.6	3.6	36%	0%	64%	4.0
REQ	33%	4.0%	1.0	44%	38%	18%	2.8	2.8	26%	53%	21%	3.4	3.4	27%	18%	55%	4.0
TRADE	37%	3.0%	1.0	39%	44%	17%	2.7	2.7	42%	41%	17%	3.3	3.3	19%	32%	49%	4.0
ARCH	40%	0.2%	1.0	45%	44%	11%	2.7	2.7	29%	42%	29%	3.3	3.3	23%	31%	46%	4.0
TS	36%	3.0%	1.0	40%	53%	7%	2.8	2.8	33%	40%	27%	3.2	3.2	27%	27%	46%	4.0
PI	21%	16.0%	1.0	36%	54%	14%	1.5	1.5	33%	38%	29%	3.5	3.5	29%	29%	42%	4.0
VER	25%	9.0%	1.0	31%	62%	7%	2.7	2.7	33%	34%	33%	3.2	3.2	33%	20%	47%	4.0
VAL	28%	7.0%	1.0	54%	23%	23%	2.7	2.7	17%	66%	17%	3.3	3.3	29%	33%	38%	4.0
CM	13%	26.0%	1.0	29%	47%	24%	3.0	3.0	46%	36%	18%	3.67	3.67	28%	33%	39%	4.0
Overall SEC	32%	4.0%	1.0	39%	46%	15%	2.5	2.5	29%	59%	12%	3.0	3.0	31%	13%	56%	4.0
REQ+TS	49%	0.5%	1.0	43%	50%	13%	2.8	2.8	23%	62%	15%	3.1	3.1	22%	28%	50%	4.0
Acquirer Capability																	
AC	-35%	3.0%	1.0	7%	60%	33%	2.5	2.5	41%	32%	26%	3.0	3.0	50%	25%	25%	4.0
Combined Capability and Challenge																	
REQ+TS+PC	63%	0.0%	1.0	67%	33%	0%	1.7	1.7	25%	45%	30%	2.3	2.3	14%	36%	50%	4.0

Gamma relationship	Chance probability
Strong	Very low
Moderately strong to strong	Low

Gamma relationship	Chance probability
Moderately strong	Moderately low
Weak	Fair

Summary SE Relationships to Project Performance

Relative Project Performance

Details

	Gamma	p	Lower Min. Range	Lower # Lo	Lower # Med	Lower # Hi	Lower Max. Range	Moderate Min. Range	Moderate # Lo	Moderate # Med	Moderate # Hi	Moderate Max. Range	Higher Min. Range	Higher # Lo	Higher # Med	Higher # Hi	Higher Max. Range
Project Challenge																	
PC	-31%	5.0%	1.0	22%	28%	50%	1.85	1.85	42%	58%	0%	2.05	2.05	38%	38%	25%	4.0
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REQ	33%	4.0%	1.0	44%	38%	18%	2.8	2.8	26%	53%	21%	3.4	3.4	27%	18%	55%	4.0
TRADE	37%	3.0%	1.0	39%	44%	17%	2.7	2.7	42%	41%	17%	3.3	3.3	19%	32%	49%	4.0
ARCH	40%	0.2%	1.0	45%	44%	11%	2.7	2.7	29%	42%	29%	3.3	3.3	23%	31%	46%	4.0
TS	36%	3.0%	1.0	40%	53%	7%	2.8	2.8	33%	40%	27%	3.2	3.2	27%	27%	46%	4.0
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VER	25%	9.0%	1.0	31%	62%	7%	2.7	2.7	33%	34%	33%	3.2	3.2	33%	20%	47%	4.0
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Acquirer Capability																	
AC	-35														25%	25%	4.0
Combined Capability and																	
REQ+TS+PC	63														36%	50%	4.0

Highest scoring SE capability areas in Higher Performing Projects*:
Risk Management; Requirements Development and Management; IPTs

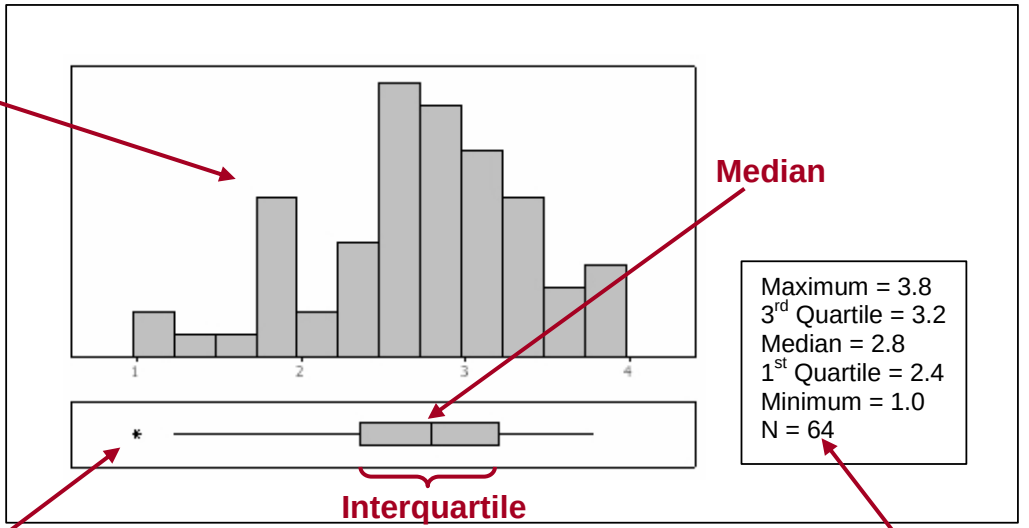
*Based on small partitioned sample size

Lowest scoring SE capability areas in Lower Performing Projects*:
Validation; Architecture; Requirements Development and Management

Gamma relationship	Chance probability
Strong	Very low
Moderately strong to strong	Low

Gamma relationship	Chance probability
Moderately strong	Moderately low
Weak	Fair

Terminology and Notation
Distribution Graph



Histogram of response frequencies

Median

Outliers

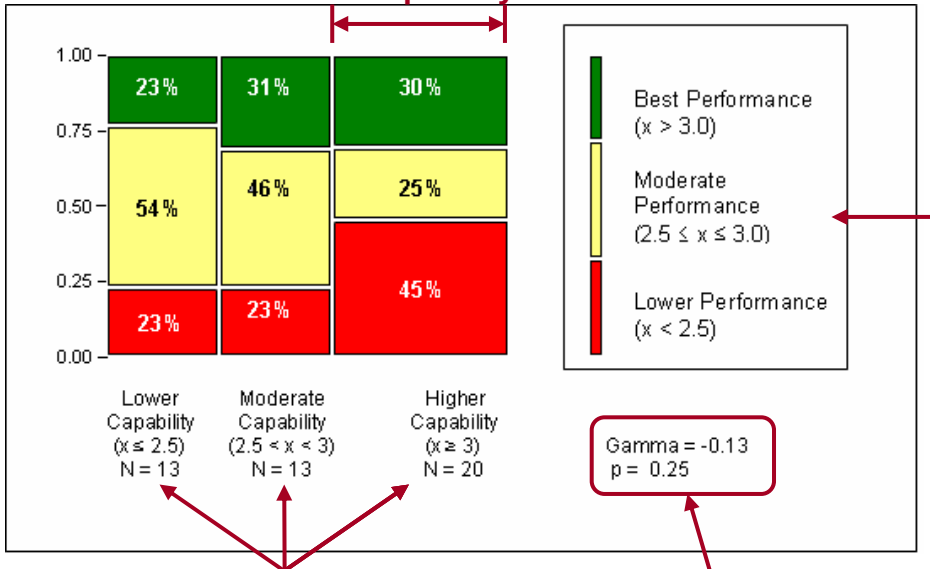
Interquartile Range

Data Range

Sample size (responses to corresponding survey questions)

Terminology and Notation
Mosaic Chart

Column width represents proportion of projects with this level of capability



Relative performance distribution of the sample

Gamma: measures strength of relationship between two ordinal variables

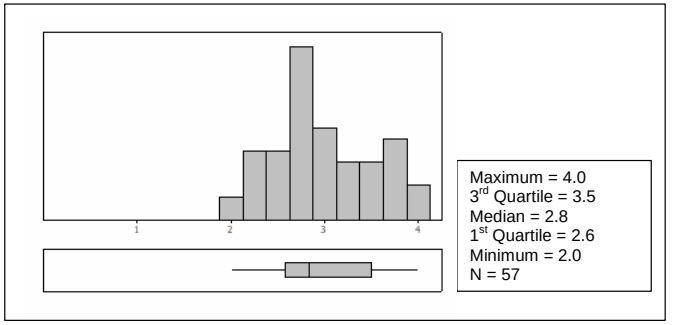
p: probability that an associative relationship would be observed by chance alone

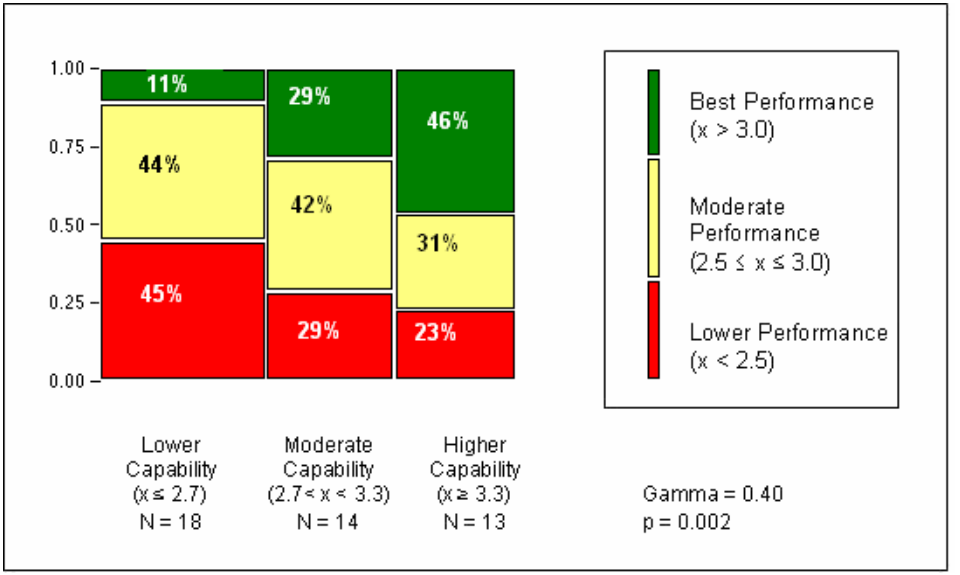
Projects exhibiting a given level of relative capability (Lowest, Intermediate, Highest)

Sample size and distribution for associated survey responses (capability + performance)

Measures of association and statistical test

SE Capability:
Product Architecture (ARCH)





Relationship to project performance:	Moderately strong to strong positive relationship

SE Capability

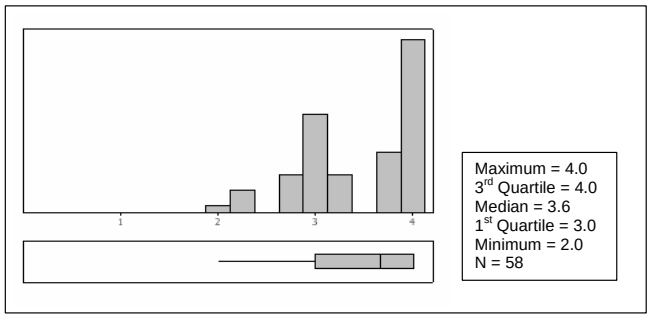
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
ARCH	40%	0.2%	1.0	45%	44%	11%	2.7	2.7	29%	42%	29%	3.3	3.3	23%	31%	46%	4.0

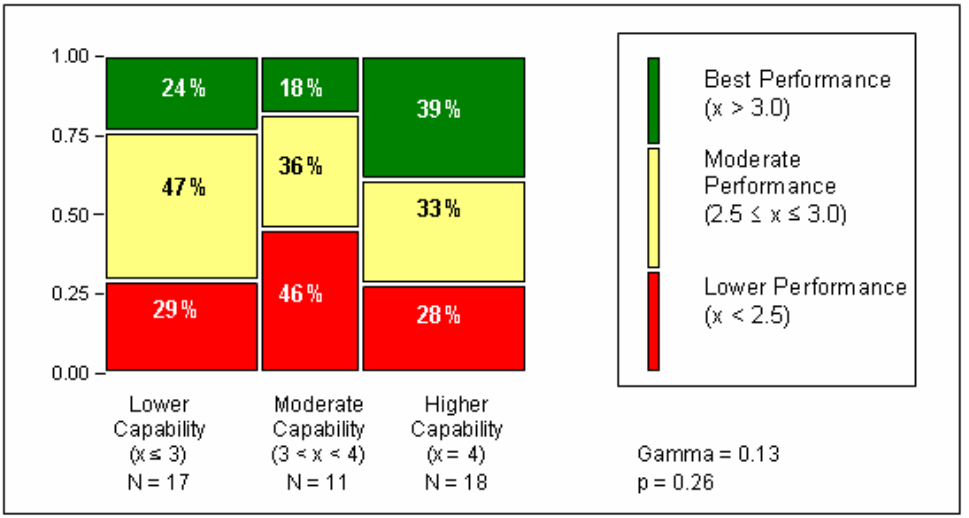
SE Capability: Product Architecture (ARCH)

Survey Questions

ID	Question	Response range
IF01	This project maintains accurate and up-to-date descriptions (e.g. interface control documents, models, etc.) defining interfaces in detail	•strongly disagree •disagree •agree •strongly agree
IF02	Interface definition descriptions are maintained in a designated location, under configuration management, and accessible to all who need them	•strongly disagree •disagree •agree •strongly agree
IF03a	For this project, the product high-level structure is documented, kept up to date, and managed under configuration control	•strongly disagree •disagree •agree •strongly agree
IF03b	For this project, the product high-level structure is documented using multiple views (e.g. functional views, module views, etc.	•strongly disagree •disagree •agree •strongly agree
IF03c	For this project, the product high-level structure is accessible to all relevant project personnel	•strongly disagree •disagree •agree •strongly agree
IF04	This project has defined and documented guidelines for choosing COTS product components	•strongly disagree •disagree •agree •strongly agree

SE Capability:
Configuration Management (CM)





Relationship to project performance:	Weak positive relationship

SE Capability

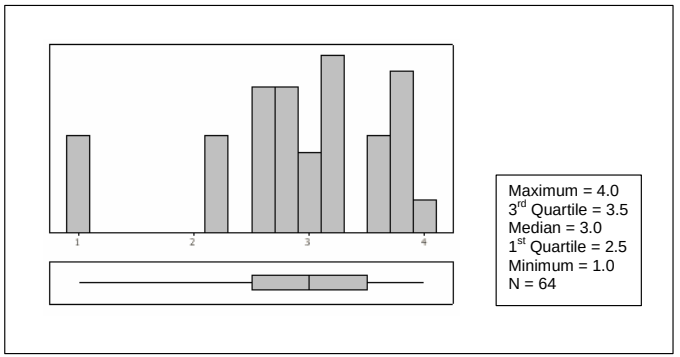
	Gamma	p	Lower Min. Range	Lower # Lo	Lower # Med	Lower # Hi	Lower Max. Range	Moderate Min. Range	Moderate # Lo	Moderate # Med	Moderate # Hi	Moderate Max. Range	Higher Min. Range	Higher # Lo	Higher # Med	Higher # Hi	Higher Max. Range
CM	13%	26.0%	1.0	29%	47%	24%	3.0	3.0	46%	36%	18%	3.67	3.67	28%	33%	39%	4.0

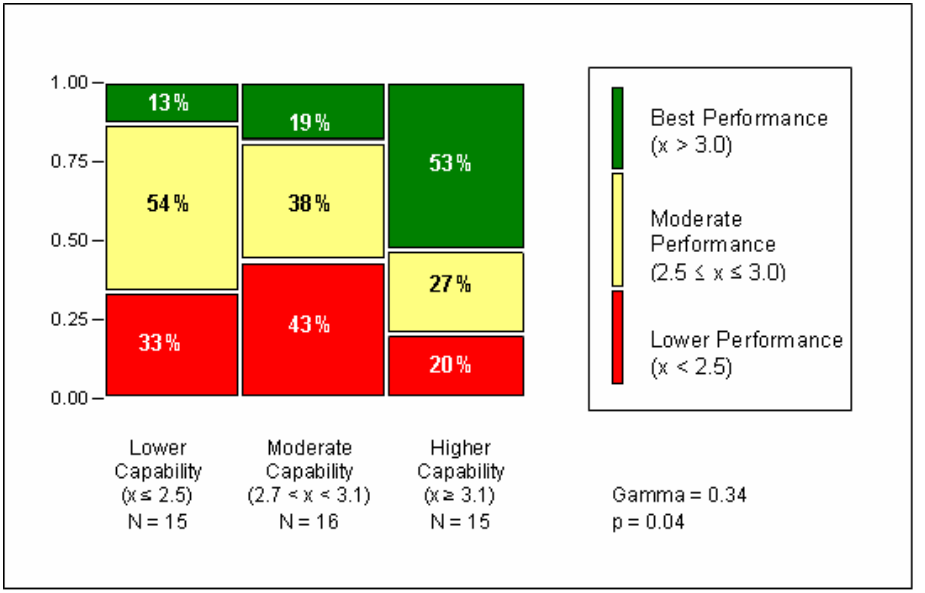
SE Capability: Configuration Management (CM)

Survey Questions

ID	Question	Response Range
V&V06	This project has a configuration management system that charters a Change Control Board to disposition change requests	•strongly disagree •disagree •agree •strongly agree
V&V07	This project maintains records of requested and implemented changes to configuration-managed items	•strongly disagree •disagree •agree •strongly agree
V&V08	This project creates and manages configuration baselines (e.g., functional, allocated, product)	•strongly disagree •disagree •agree •strongly agree

SE Capability:
IPT-Related Capability (IPT)





Relationship to project performance:	Moderately strong positive relationship

SE Capability

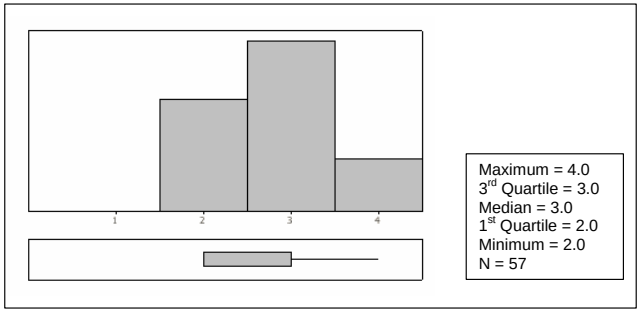
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
IPT	34%	4.0%	1.0	33%	54%	13%	2.5	2.5	43%	38%	19%	3.1	3.1	20%	27%	53%	4.0

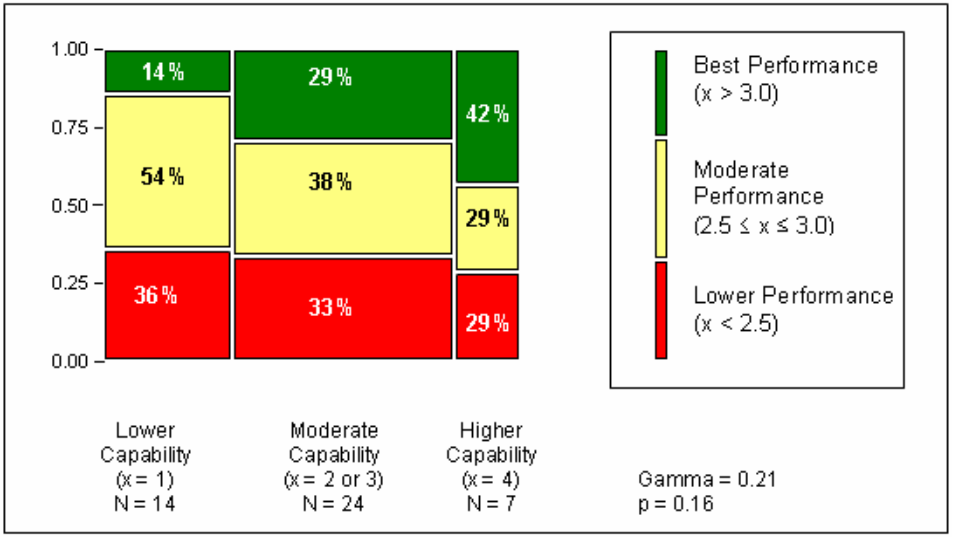
SE Capability:
IPT-Related Capability (IPT)

Survey Questions

ID	Question	Response range
Proj03	This project uses integrated product teams (IPTs)	•Yes •No
Proj04	This project makes effective use of integrated product teams (IPTs)	•highly compliant •largely compliant; •moderately compliant •not compliant
Proj06	My suppliers actively participate in IPTs	•highly compliant •largely compliant; •moderately compliant •not compliant
Proj07a	This project has an IPT with assigned responsibility for systems engineering	•highly compliant •largely compliant; •moderately compliant •not compliant
Proj07b	This project has Systems Engineering representation on each IPT	•highly compliant •largely compliant; •moderately compliant •not compliant

SE Capability:
Product Integration (PI)





Relationship to project performance:	Weak positive relationship

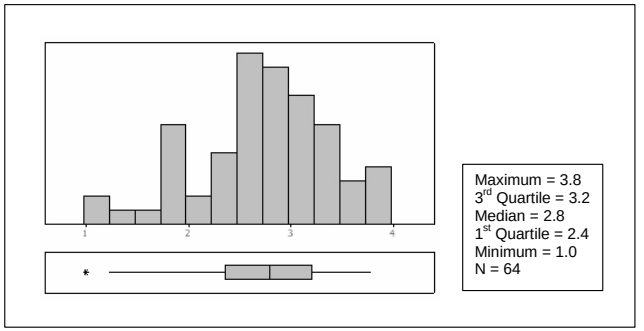
SE Capability

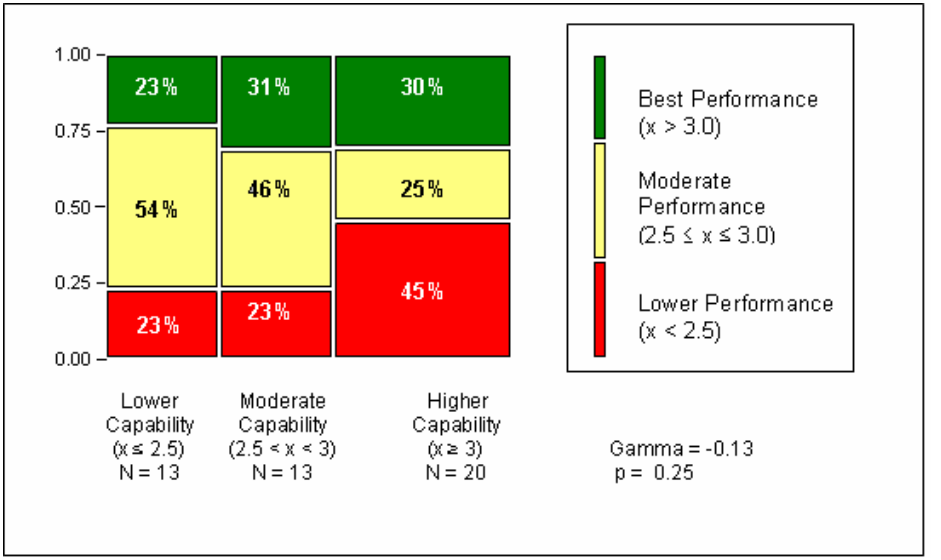
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
PI	21%	16.0%	1.0	36%	54%	14%	1.5	1.5	33%	38%	29%	3.5	3.5	29%	29%	42%	4.0

Survey Question

ID	Question	Response range
IF05	This project has accurate and up-to-date documents defining its product integration process, plans, criteria, etc. throughout the life cycle	•strongly disagree •disagree •agree •strongly agree

SE Capability:
Project Monitoring and Control (PMC)





Relationship to project performance:	Weak negative relationship

SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
PMC	-13%	25.0%	1.0	23%	54%	23%	2.5	2.5	23%	46%	31%	3.0	3.0	45%	25%	30%	4.0

SE Capability:
Project Monitoring and Control (PMC)

Survey Questions (Part 1)

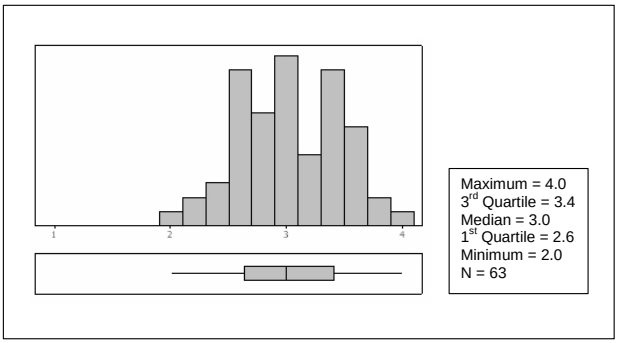
ID	Question	Response range
Cont13	Do you separately cost and track systems engineering activities?	Yes No
Cont14a	Approximately what percentage of non-recurring engineering (NRE) does systems engineering represent?	Percentages quantized as: •<= 5% •<= 10% •<= 15% •<= 25% •> 25%
Cont14b	Is the NRE percentage estimated, or is it a measured value?	•estimated •measured
Perf01	This project creates and manages cost and schedule baselines	•strongly disagree •disagree •agree •strongly agree
Perf02b	EVMS data are available to decision makers in a timely manner (i.e. current within 2 weeks)	•strongly disagree •disagree •agree •strongly agree
Perf02c	The requirement to track and report EVMS data is levied upon the project's suppliers	•strongly disagree •disagree •agree •strongly agree
Perf02d	Variance thresholds for CPI and SPI variance are defined, documented, and used to determine when corrective action is needed	•strongly disagree •disagree •agree •strongly agree

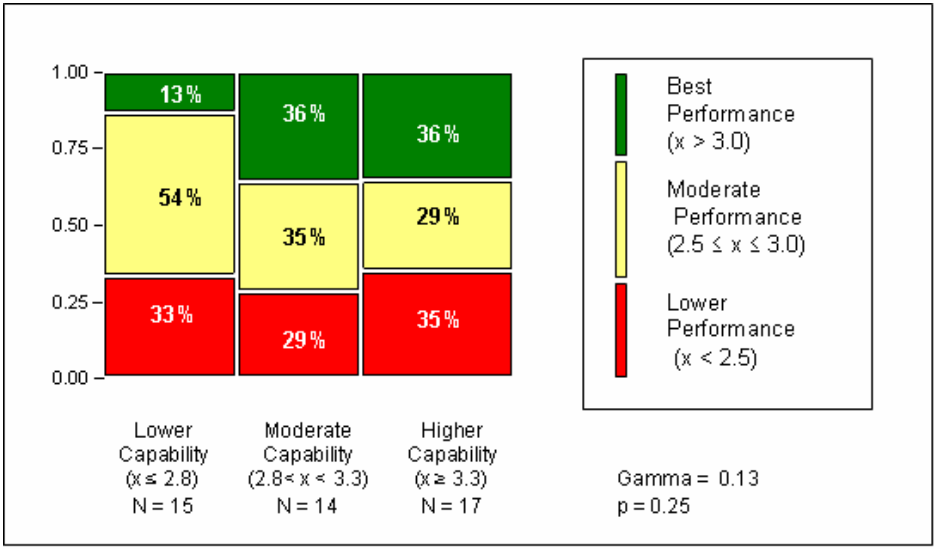
SE Capability:
Project Monitoring and Control (PMC)

Survey Questions (Part 2)

ID	Question	Response range	
Perf02e	EVMS is linked to the technical effort through the WBS and the IMP/IMS	•strongly disagree •disagree •agree •strongly agree	
OPerf05	Does this project track reports of problems from fielded items?	•Yes •No	Scored by the number of positive responses
OPerf06	Does the project conduct an engineering assessment of all field trouble reports?	•Yes •No	
OPerf07	The results of this engineering assessment feed into …	•operational hazard risk assessments •materiel readiness assessments •system upgrades planning •other	

SE Capability:
Project Planning (PP)





Relationship to project performance:	Weak positive relationship

SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
PP	13%	25.0%	1.0	33%	54%	13%	2.8	2.8	29%	35%	36%	3.3	3.3	35%	29%	36%	4.0

Survey Questions (Part 1)

ID	Question	Response range
PD01	This project utilizes a documented set of systems engineering processes for the planning and execution of the project	•strongly disagree •disagree •agree •strongly agree
PD02a	This project has an accurate and up-to-date Work Breakdown Structure (WBS) that includes task descriptions and work package descriptions	•strongly disagree •disagree •agree •strongly agree
PD02b	This project has an accurate and up-to-date Work Breakdown Structure (WBS) that is based upon the product structure	•strongly disagree •disagree •agree •strongly agree
PD02c	This project has an accurate and up-to-date Work Breakdown Structure (WBS) that is developed with the active participation of those who perform the systems engineering activities	•strongly disagree •disagree •agree •strongly agree
PD02d	This project has an accurate and up-to-date Work Breakdown Structure (WBS) that is developed with the active participation of all relevant stakeholders, e.g., developers, maintainers, testers, inspectors, etc.	•strongly disagree •disagree •agree •strongly agree
PD03a	This project's Technical Approach (i.e. a top-level strategy and methodology to create the initial conceptual design for product development) is complete, accurate and up-to-date	•strongly disagree •disagree •agree •strongly agree
PD03b	This project's Technical Approach (i.e. a top-level strategy and methodology to create the initial conceptual design for product development) is developed with the active participation of those who perform the systems engineering activities	•strongly disagree •disagree •agree •strongly agree
PD03c	This project's Technical Approach (i.e. a top-level strategy and methodology to create the initial conceptual design for product development) is developed with the active participation of all appropriate functional stakeholder	•strongly disagree •disagree •agree •strongly agree

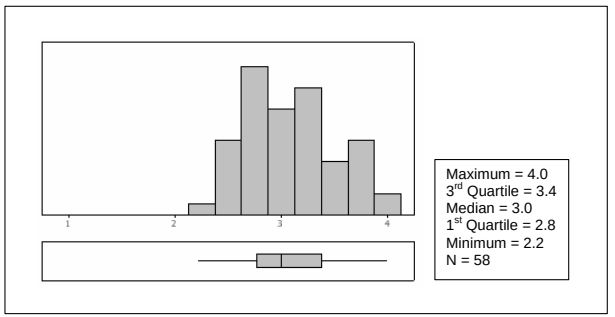
Survey Questions (Part 2)

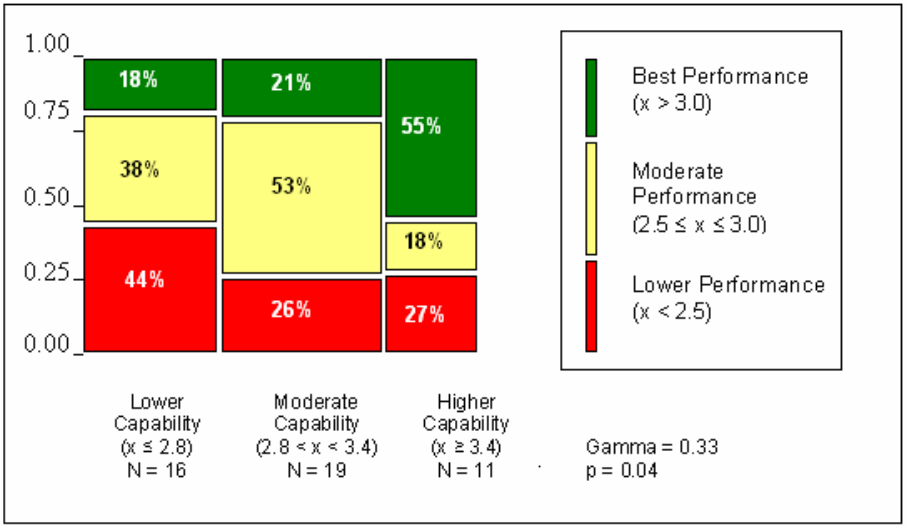
ID	Question	Response range
PD04a	This project has a top-level plan, such as an Integrated Master Plan (IMP), that is an event-driven plan (i.e., each accomplishment is tied to a key project event)	•strongly disagree •disagree •agree •strongly agree
PD04b	This project has a top-level plan, such as an Integrated Master Plan (IMP), that documents significant accomplishments with pass/fail criteria for both business and technical elements of the project	•strongly disagree •disagree •agree •strongly agree
PD04c	This project has a top-level plan, such as an Integrated Master Plan (IMP), that is consistent with the WBS	•strongly disagree •disagree •agree •strongly agree
PD05a	This project has an integrated event-based schedule that is structured as a networked, multi-layered schedule of project tasks required to complete the work effort	•strongly disagree •disagree •agree •strongly agree
PD05b	This project has an integrated event-based schedule that contains a compilation of key technical accomplishments (e.g., a Systems Engineering Master Schedule)	•strongly disagree •disagree •agree •strongly agree
PD05c	This project has an integrated event-based schedule that references measurable criteria (usually contained in the Integrated Master Plan) required for successful completion of key technical accomplishments	•strongly disagree •disagree •agree •strongly agree
PD05d	This project has an integrated event-based schedule that is consistent with the WBS	•strongly disagree •disagree •agree •strongly agree

Survey Questions (Part 3)

ID	Question	Response range
PD05e	This project has an integrated event-based schedule that identifies the critical path of the program schedule	•strongly disagree •disagree •agree •strongly agree
PD06	This project has a plan or plans for the performance of technical reviews with defined entry and exit criteria throughout the life cycle of the project	•strongly disagree •disagree •agree •strongly agree
PD07	This project has a plan or plans that include details of the management of the integrated technical effort across the project (e.g., a Systems Engineering Management Plan or a Systems Engineering Plan)	•strongly disagree •disagree •agree •strongly agree
PD08	Those who perform systems engineering activities actively participate in the development and updates of the project planning	•strongly disagree •disagree •agree •strongly agree
PD09	Those who perform systems engineering activities actively participate in tracking/reporting of task progress	•strongly disagree •disagree •agree •strongly agree

SE Capability:
Requirements Development & Mgmt (REQ)





Relationship to project performance:	Moderately strong positive relationship

SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
REQ	33%	4.0%	1.0	44%	38%	18%	2.8	2.8	26%	53%	21%	3.4	3.4	27%	18%	55%	4.0

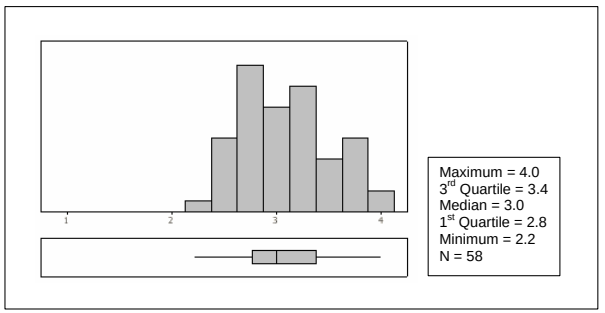
Survey Questions (Part 1)

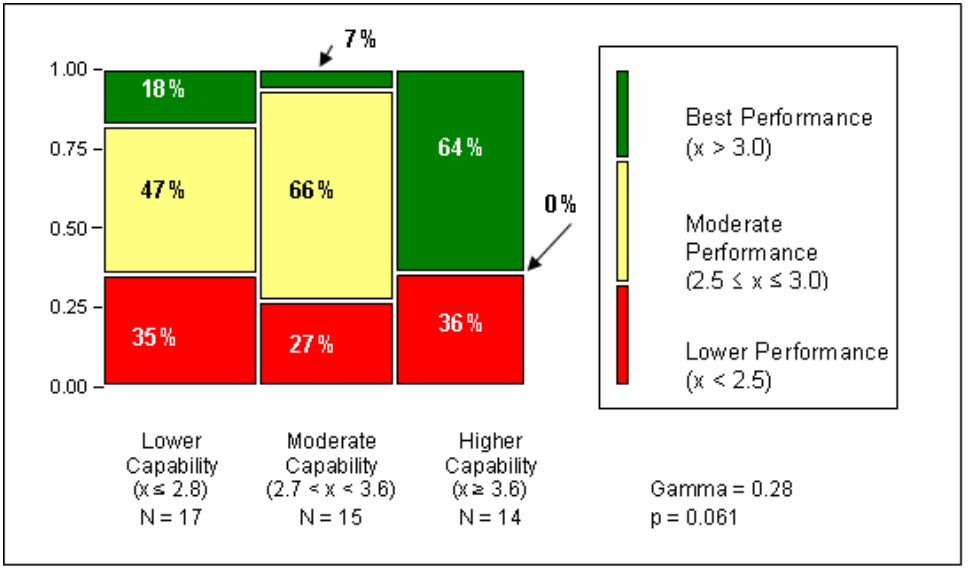
ID	Question	Response range
RD01a	This project maintains an up-to-date and accurate listing of all requirements specified by the customer, to include regulatory, statutory, and certification requirements	•strongly disagree •disagree •agree •strongly agree
RD01b	This project maintains an up-to-date and accurate listing of all requirements derived from those specified by the customer	•strongly disagree •disagree •agree •strongly agree
RD02	This project maintains up-to-date and accurate documentation clearly reflecting the hierarchical allocation of both customer and derived requirements to each element (subsystem, component, etc.) of the system in the configuration baselines	•strongly disagree •disagree •agree •strongly agree
RD03a	This project documents and maintains accurate and up-to-date descriptions of operational concepts and their associated scenarios	•strongly disagree •disagree •agree •strongly agree
RD03b	This project documents and maintains accurate and up-to-date descriptions of use cases (or their equivalent)	•strongly disagree •disagree •agree •strongly agree
RD03c	This project documents and maintains accurate and up-to-date descriptions of product installation, maintenance and support concepts	•strongly disagree •disagree •agree •strongly agree
RD04	This project has documented criteria for identifying authorized requirements providers to avoid requirements creep and volatility	•strongly disagree •disagree •agree •strongly agree

Survey Questions (Part 2)

ID	Question	Response range
RD05	This project has documented criteria (e.g., cost impact, schedule impact, authorization of source, contract scope, requirement quality) for evaluation and acceptance of requirements	•strongly disagree •disagree •agree •strongly agree
RD06	The requirements for this project are approved in a formal and documented manner by relevant stakeholders	•strongly disagree •disagree •agree •strongly agree
RD07	This project performs and documents requirements impact assessments for proposed requirements changes	•strongly disagree •disagree •agree •strongly agree
RD08	This project develops and documents project requirements based upon stakeholder needs, expectations, and constraints	•strongly disagree •disagree •agree •strongly agree
RD09	This project has an accurate and up-to-date requirements tracking system	•strongly disagree •disagree •agree •strongly agree
RD10a	For this project, the requirements documents are managed under a configuration control process	•strongly disagree •disagree •agree •strongly agree
RD10b	For this project, the requirements documents are accessible to all relevant project staff	•strongly disagree •disagree •agree •strongly agree

SE Capability:
Risk Management (RSKM)





Relationship to project performance:	Moderately strong positive relationship

SE Capability

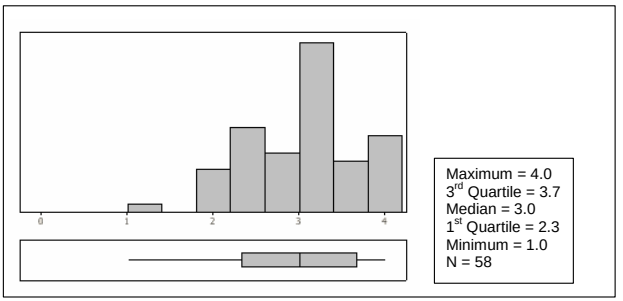
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
RSKM	28%	6.1%	1.0	35%	47%	18%	2.8	2.8	27%	66%	7%	3.6	3.6	36%	0%	64%	4.0

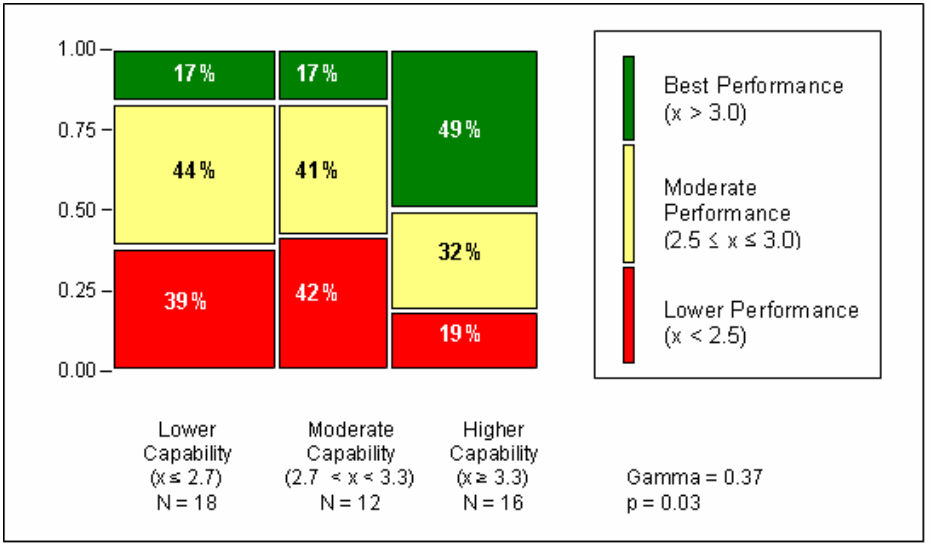
SE Capability: Risk Management (RSKM)

Survey Questions

ID	Question	Response range
PD11a	This project has a Risk Management process that creates and maintains an accurate and up-to-date list of risks affecting the project (e.g., risks to cost, risks to schedule, risks to performance)	•strongly disagree •disagree •agree •strongly agree
PD11b	This project has a Risk Management process that creates and maintains up-to-date documentation of risk mitigation plans and contingency plans for selected risks	•strongly disagree •disagree •agree •strongly agree
PD11c	This project has a Risk Management process that monitors and reports the status of risk mitigation activities and resources	•strongly disagree •disagree •agree •strongly agree
PD11d	This project has a Risk Management process that assesses risk against achievement of an event-based schedule	•strongly disagree •disagree •agree •strongly agree
PD12	This project's Risk Management process is integrated with program decision-making	•strongly disagree •disagree •agree •strongly agree

SE Capability: Trade Studies (TRADE)





Relationship to project performance:	Moderately strong to strong positive relationship

SE Capability

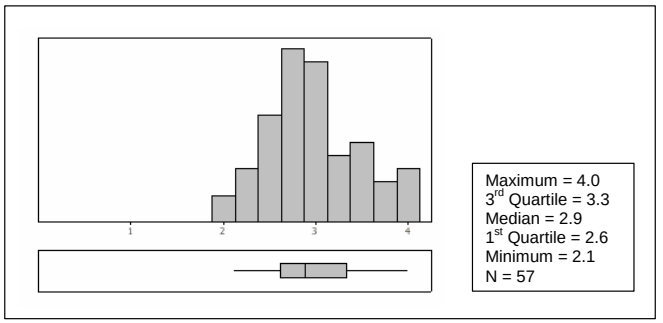
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
TRADE	37%	3.0%	1.0	39%	44%	17%	2.7	2.7	42%	41%	17%	3.3	3.3	19%	32%	49%	4.0

SE Capability: Trade Studies (TRADE)

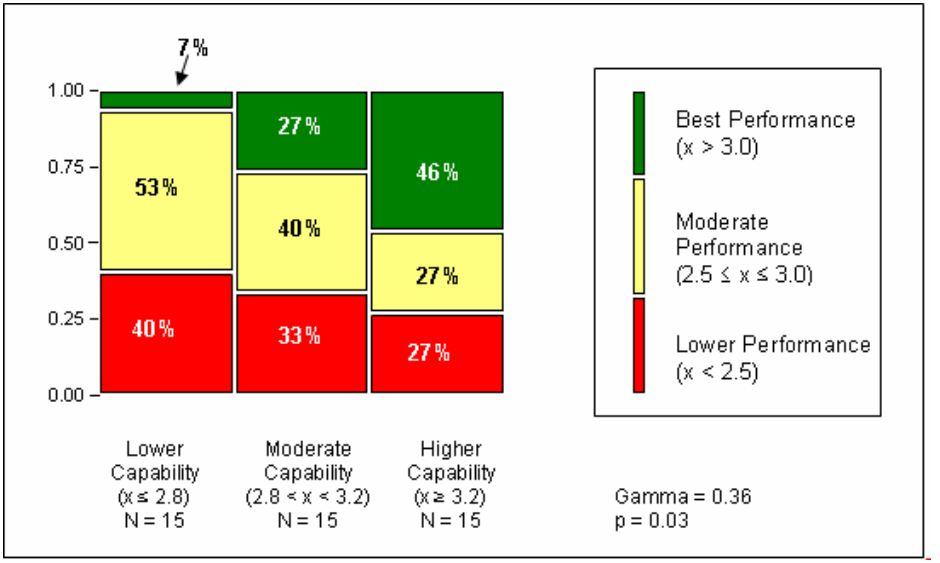
Survey Questions

ID	Question	Response range
RD11	Stakeholders impacted by trade studies are involved in the development and performance of those trade studies	•strongly disagree •disagree •agree •strongly agree
RD12	This project performs and documents trade studies between alternate solutions based upon definitive and documented selection criteria	•strongly disagree •disagree •agree •strongly agree
RD13	Documentation of trade studies is maintained in a defined repository and is accessible to all relevant project staff	•strongly disagree •disagree •agree •strongly agree

SE Capability: Technical Solution (TS)



Note: TS is a composite measure equivalent to ARCH + TRADE.



Relationship to project performance:	Moderately strong positive relationship

SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
TS	36%	3.0%	1.0	40%	53%	7%	2.8	2.8	33%	40%	27%	3.2	3.2	27%	27%	46%	4.0

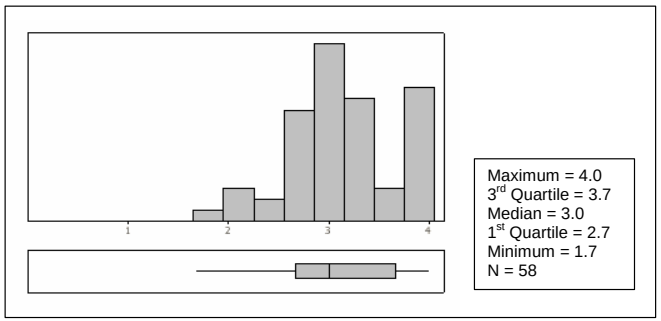
Survey Questions (Part 1)

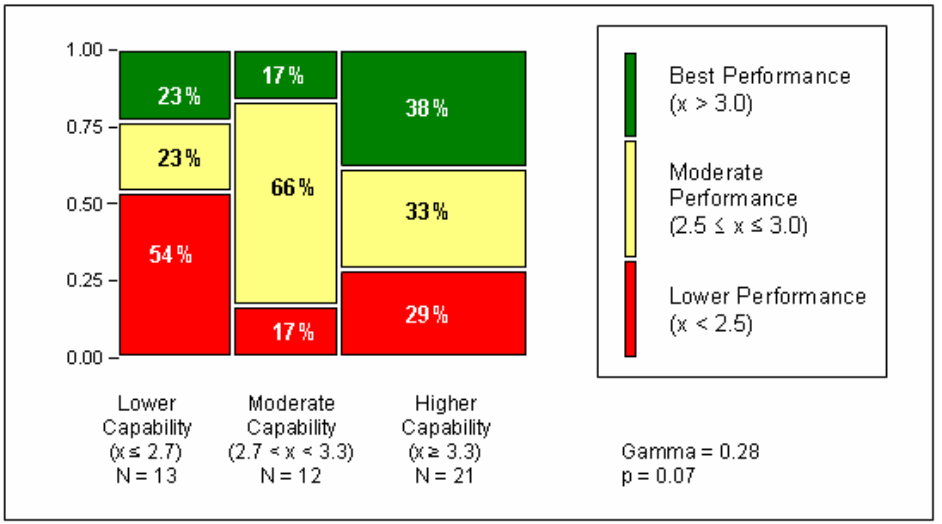
ID	Question	Response Range
RD11	Stakeholders impacted by trade studies are involved in the development and performance of those trade studies	•strongly disagree •disagree •agree •strongly agree
RD12	This project performs and documents trade studies between alternate solutions based upon definitive and documented selection criteria	•strongly disagree •disagree •agree •strongly agree
RD13	Documentation of trade studies is maintained in a defined repository and is accessible to all relevant project staff	•strongly disagree •disagree •agree •strongly agree
IF01	This project maintains accurate and up-to-date descriptions (e.g. interface control documents, models, etc.) defining interfaces in detail	•strongly disagree •disagree •agree •strongly agree
IF02	Interface definition descriptions are maintained in a designated location, under configuration management, and accessible to all who need them	•strongly disagree •disagree •agree •strongly agree

Survey Questions (Part 2)

ID	Question	Response Range
IF03a	For this project, the product high-level structure is documented, kept up to date, and managed under configuration control	•strongly disagree •disagree •agree •strongly agree
IF03b	For this project, the product high-level structure is documented using multiple views (e.g. functional views, module views, etc.)	•strongly disagree •disagree •agree •strongly agree
IF03c	For this project, the product high-level structure is accessible to all relevant project personnel	•strongly disagree •disagree •agree •strongly agree
IF04	This project has defined and documented guidelines for choosing COTS product components	•strongly disagree •disagree •agree •strongly agree

SE Capability: Validation (VAL)





Relationship to project performance:	Moderately strong positive relationship

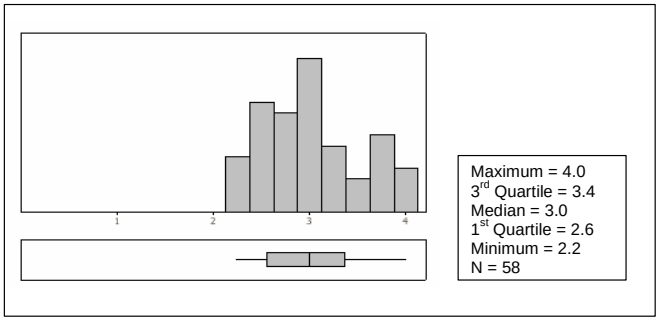
SE Capability

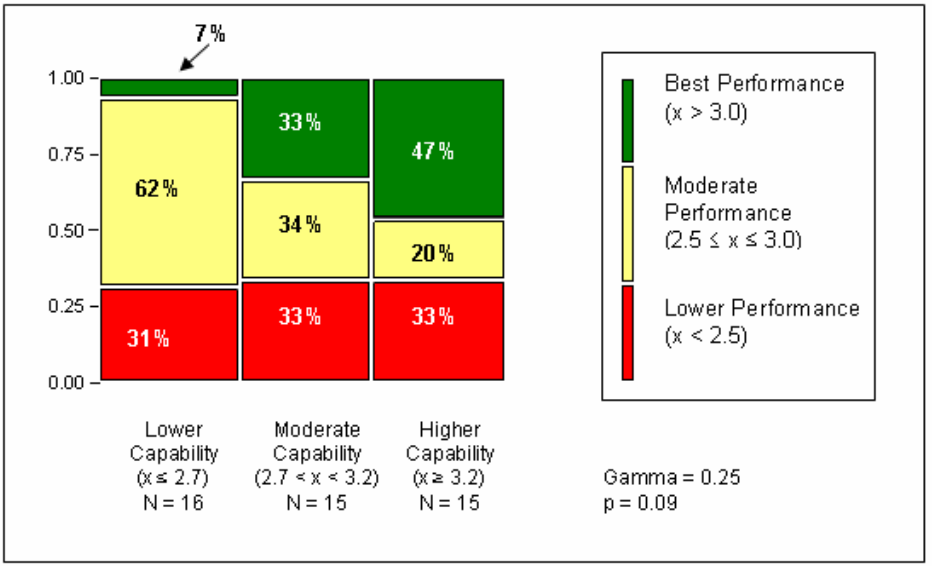
	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
VAL	28%	7.0%	1.0	54%	23%	23%	2.7	2.7	17%	66%	17%	3.3	3.3	29%	33%	38%	4.0

Survey Questions

ID	Question	Response Rate
V&V04a	This project has accurate and up-to-date documents defining the procedures used for the validation of systems and system elements	•strongly disagree •disagree •agree •strongly agree
V&V04b	This project has accurate and up-to-date documents defining acceptance criteria used for the validation of systems and system elements	•strongly disagree •disagree •agree •strongly agree
V&V05	This project maintains a listing of items managed under configuration control	•strongly disagree •disagree •agree •strongly agree

SE Capability: Verification (VER)





Relationship to project performance:	Moderately strong positive relationship

SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
VER	25%	9.0%	1.0	31%	62%	7%	2.7	2.7	33%	34%	33%	3.2	3.2	33%	20%	47%	4.0

Survey Questions (Part 1)

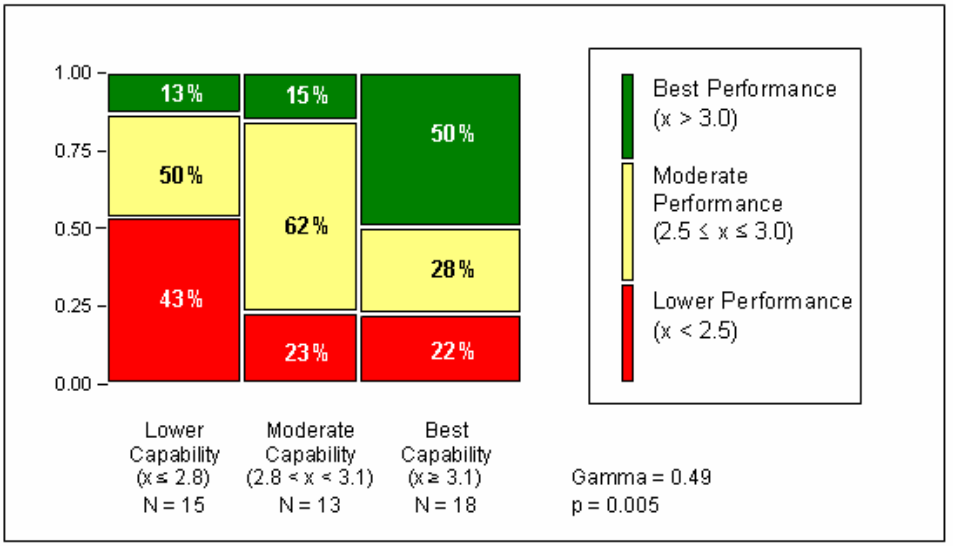
ID	Question	Response range
V&V01a	This project has accurate and up-to-date documents defining the procedures used for the test and verification of systems and system elements	•strongly disagree •disagree •agree •strongly agree
V&V01b	This project has accurate and up-to-date documents defining acceptance criteria used for the verification of systems and system elements	•strongly disagree •disagree •agree •strongly agree
V&V02a	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that defines entry and exit criteria for work products	•strongly disagree •disagree •agree •strongly agree
V&V02b	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that includes training requirements for the reviewers	•strongly disagree •disagree •agree •strongly agree
V&V02e	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that addresses identified risks and risk mitigation activities during reviews	•strongly disagree •disagree •agree •strongly agree
V&V02f	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that examines completeness of configuration baselines	•strongly disagree •disagree •agree •strongly agree

Survey Questions (Part 2)

ID	Question	Response range
V&V03	This project conducts non-advocate reviews (e.g. reviews by qualified personnel with no connection to or stake in the project) and documents results, issues, action items, risks, and risk mitigations	•strongly disagree •disagree •agree •strongly agree
V&V02c	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that defines criteria for the selection of work products (e.g., requirements documents, test plans, system design documents, etc.) for review	•strongly disagree •disagree •agree •strongly agree
V&V02d	This project has a documented and practiced review (e.g. peer reviews, design reviews, etc.) process that tracks action items to closure	•strongly disagree •disagree •agree •strongly agree

SE Capability: Combined Reqts+Tech Solution (REQ+TS)

(This is a higher order measure; see base measures for distribution)

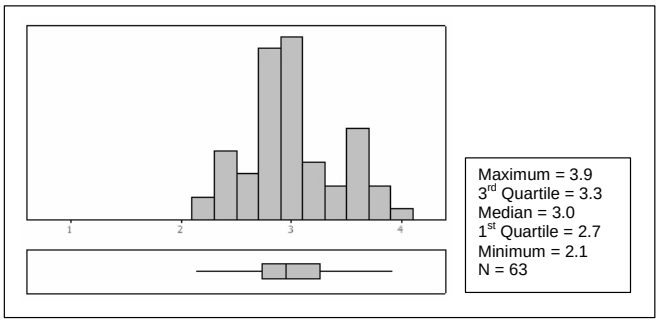


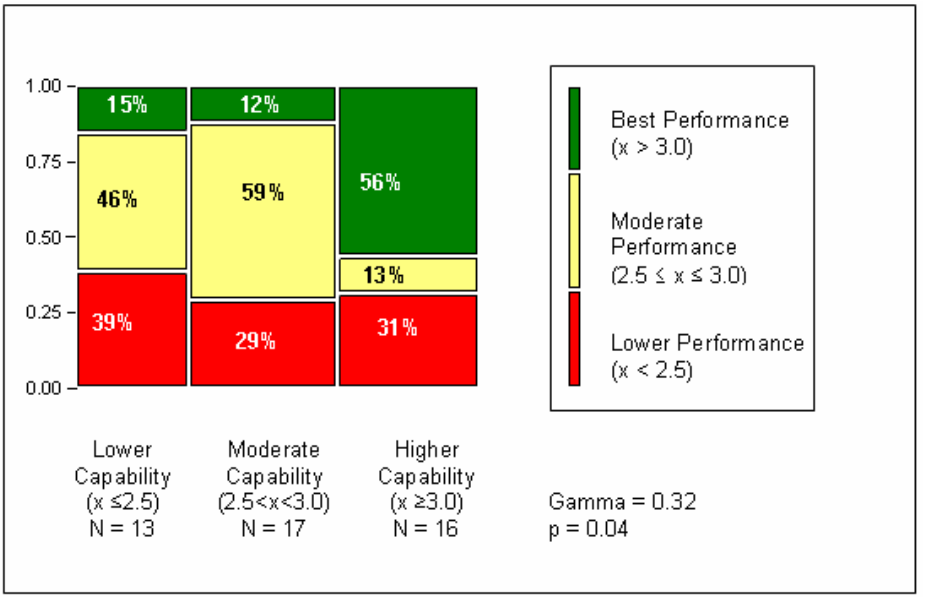
Relationship to project performance:	Strong positive relationship

SE Capability

	Gamma	p	Lower Min. Range	Lower # Lo	Lower # Med	Lower # Hi	Lower Max. Range	Moderate Min. Range	Moderate # Lo	Moderate # Med	Moderate # Hi	Moderate Max. Range	Higher Min. Range	Higher # Lo	Higher # Med	Higher # Hi	Higher Max. Range
REQ+TS	49%	0.5%	1.0	43%	50%	13%	2.8	2.8	23%	62%	15%	3.1	3.1	22%	28%	50%	4.0

SE Capability:
Total Systems Engineering Capability





Relationship to project performance:	Moderately strong positive relationship

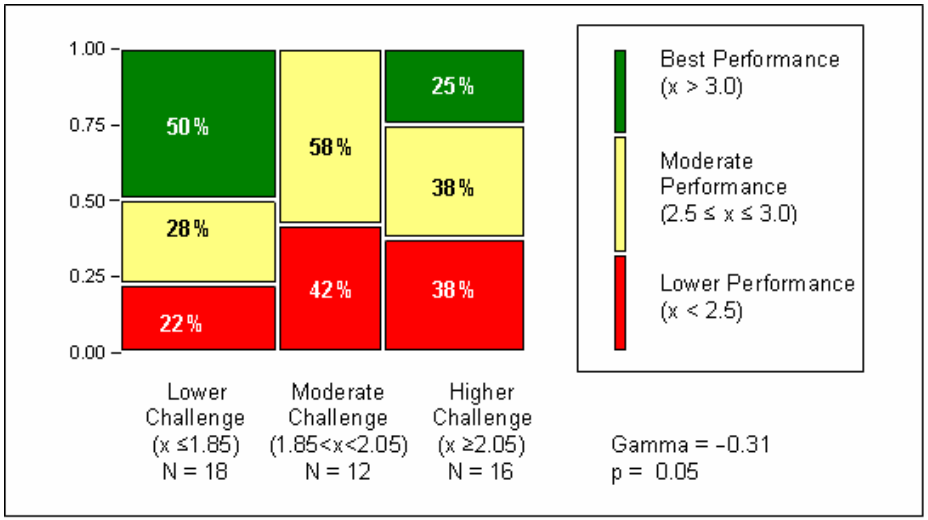
SE Capability

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
Overall SEC	32%	4.0%	1.0	39%	46%	15%	2.5	2.5	29%	59%	12%	3.0	3.0	31%	13%	56%	4.0

Project Challenge (PC)

Project challenge factors:

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

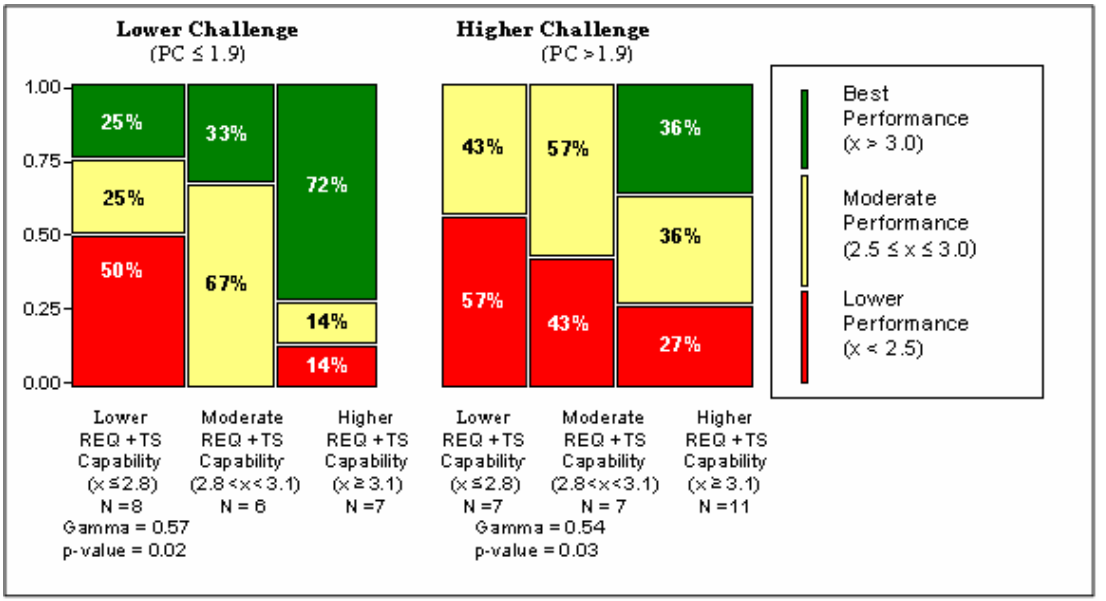


Relationship to project performance:	Moderately strong negative relationship

Project Challenge

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
PC	-31%	5.0%	1.0	22%	28%	50%	1.85	1.85	42%	58%	0%	2.05	2.05	38%	38%	25%	4.0

SE Capability: Reqts+Tech Solution with Project Challenge

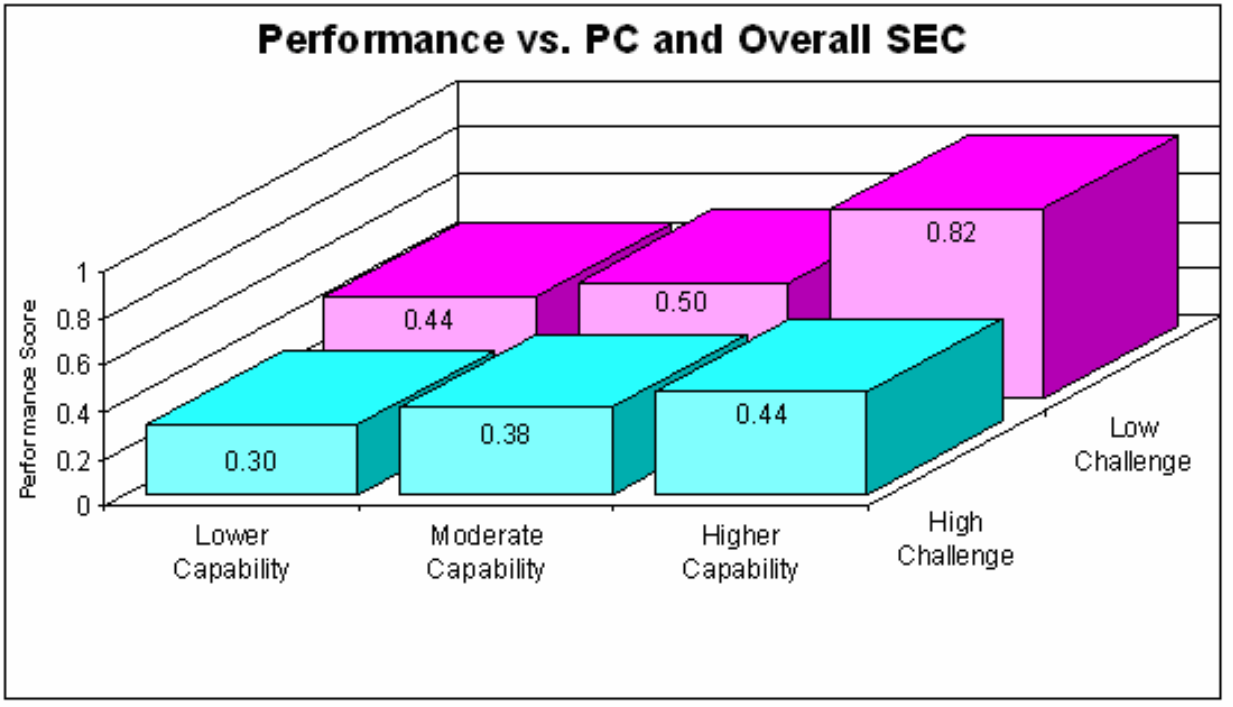


Relationship to project performance:	Very strong positive relationship

SE Capability + Project Challenge

	Gamma	p	Lower					Moderate					Higher				
			Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range	Min. Range	# Lo	# Med	# Hi	Max. Range
REQ+TS+PC	63%	0.0%	1.0	67%	33%	0%	1.7	1.7	25%	45%	30%	2.3	2.3	14%	36%	50%	4.0

Relating Project Performance to Project Challenge and SE Capability



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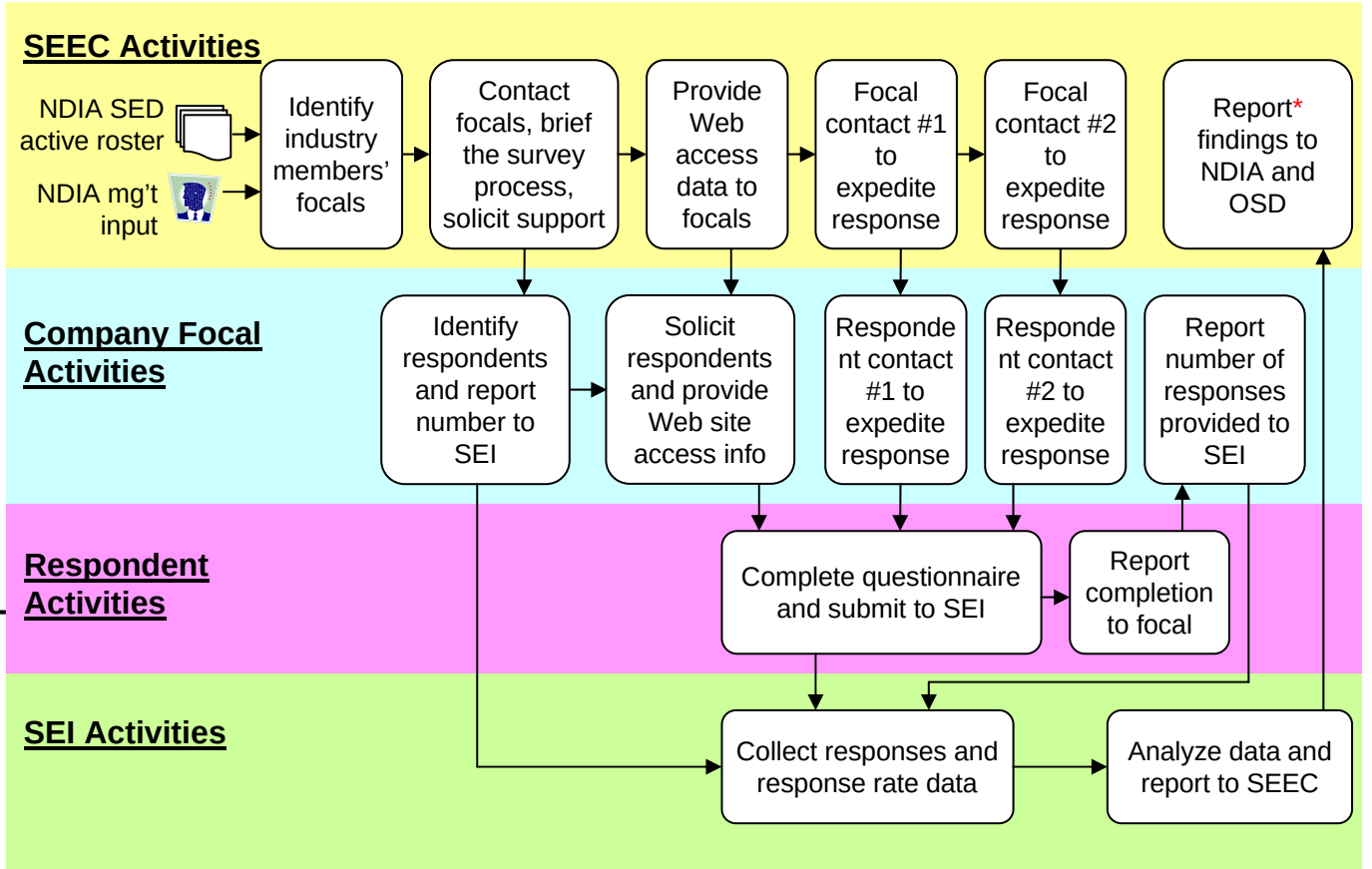
SE Effectiveness

Relationship of SEC to Performance

Supplier Systems Engineering Capability[1]	Relationship to Project Performance	Relationship (Gamma[2])	Section Reference
Project Planning	Weak positive relationship	+0.13	5.1.3.2
Project Monitoring and Control	Weak negative relationship	-0.13	5.1.3.3
Risk Management	Moderately strong positive relationship	+0.28	5.1.3.4
Requirements Development & Management	Moderately strong positive relationship	+0.33	5.1.3.5
Trade Studies	Strong positive relationship	+0.37	5.1.3.6
Product Architecture	Moderately strong to strong positive relationship	+0.40	5.1.3.7
Technical Solution	Moderately strong positive relationship	+0.36	5.1.3.8
Product Integration	Weak positive relationship	+0.21	5.1.3.9
Verification	Moderately strong positive relationship	+0.25	5.1.3.10
Validation	Moderately strong positive relationship	+0.28	5.1.3.11
Configuration Management	Weak positive correlation	+0.13	5.1.3.12
IPT-Related Capability	Moderately strong positive correlation	+0.34	5.1.3.1

SE Effectiveness
Methodology (In Detail)



SE Effectiveness

Methodology (Mathematical Statement)

$$\textbf{\textit{Perf}} = f\,(\textbf{\textit{PC}}, \textbf{\textit{PE}}, \textbf{\textit{SEC}}, \textbf{\textit{AC}})$$

***Perf* -** Project Performance
PC - Project Challenge
PE - Project Environment ***PE***
SEC - Systems Engineering Capability
AC - Acquirer Capability

Results

Summary of Relationships

Driving Factor	Relationship to Project Performance	
	Description	Γ
Requirements and Technical Solution Combined with Project Challenge	Very strong positive	+0.63
Combined Requirements and Technical Solution	Strong positive	+0.49
Product Architecture	Moderately strong to strong positive	+0.40
Trade Studies	Moderately strong to strong positive	+0.37
IPT-Related Capability	Moderately strong positive	+0.34
Technical Solution	Moderately strong positive	+0.36
Requirements Development and Management	Moderately strong positive	+0.33

Driving Factor	Relationship to Project Performance	
	Description	Γ
Total Systems Engineering Capability	Moderately strong positive	+0.32
Project Challenge	Moderately strong negative	-0.31
Validation	Moderately strong positive	+0.28
Risk Management	Moderately strong positive	+0.28
Verification	Moderately strong positive	+0.25
Product Integration	Weak positive	+0.21
Project Planning	Weak positive	+0.13
Configuration Management	Weak positive	+0.13
Process Improvement	Weak positive	+0.05
Project Monitoring and Control	Weak negative	-0.13