Effective Systems Engineering: What's the Payoff for Program Performance?

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Carnegie Mellon University

in collaboration with the

National Defense Industrial Association (NDIA)

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 program risks.

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

… optimize the design through evaluation of alternate solutions.

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

… including SE costs in the 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.

… it doesn't produce deliverable outputs.

… the customer won't pay for them.

These are the ASSERTIONS, but what are the FACTS?

The Problem

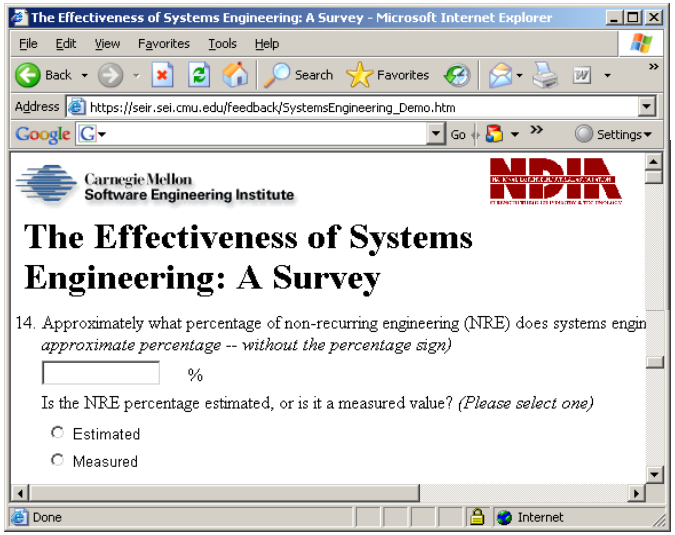
It is difficult to justify the costs of SE in terms that program managers and corporate managers can relate to.

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

How can we quantify the effectiveness and value of SE?
How does SE benefit program performance?

Systems Engineering Effectiveness Survey (2004-2007)

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



Objectives:

- Characterize effective SE practices
- Correlate SE practices with measures of program performance

Approach:

- Distribute survey to NDIA companies
- SEI analysis and correlation of responses

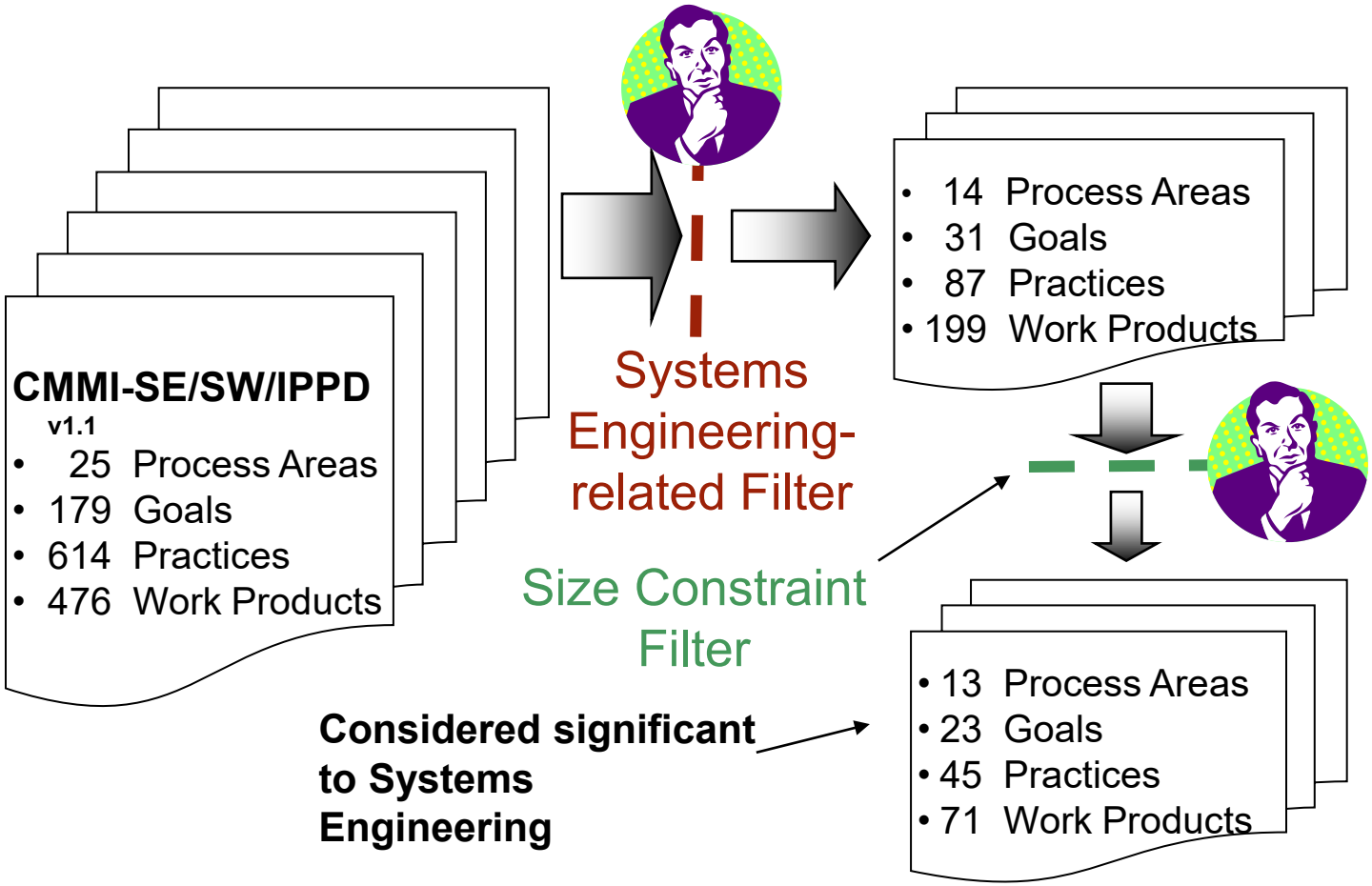
Survey Areas:

Process definition
Project planning
Risk management
Requirements development
Requirements management

Trade studies
Interfaces
Product structure
Product integration
Test and verification

Project reviews
Validation
Configuration mgmt
Metrics

Survey Development

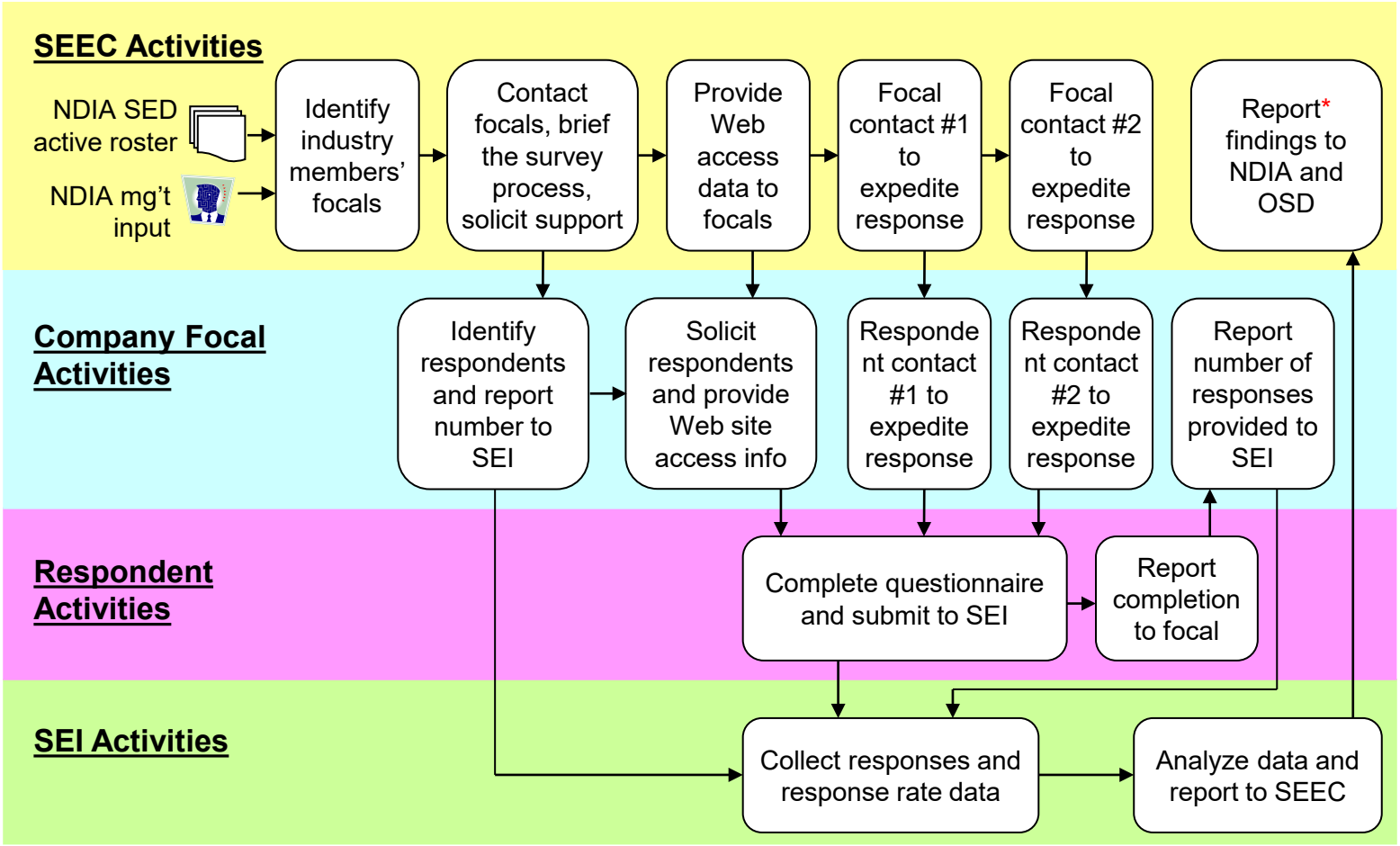


Survey content is based on a recognized standard (CMMI)

Survey Methodology
(Conducted: 2004-2007)

Survey Population	Organizations developing products in support of government contracts (prime or subcontractors).
Sampling Method	Invitation to qualifying active members of NDIA Systems Engineering Division. Random sampling within organization.
Survey Deployment	Web deployment (open August 10, 2006 - November 30, 2006). Anonymous response. Questions based on CMMI-SE/SW v1.1.
Target Respondent	Program Manager or designee(s) from individual projects
Questionnaire Structure	1. Characterization of the project /program under consideration 2. Evidence of Systems Engineering Best Practices 3. Project / Program Performance Metrics
Target Response Time	30 – 60 minutes
Responses	64 survey responses (46 complete; 18 partial, but usable)
Analysis	Raw data analyzed by Software Engineering Institute. Analysis results reviewed by NDIA SE Effectiveness Committee.
Reports	Public NDIA/SEI report. Restricted attachment with details provided to respondents only.

SE Effectiveness
Methodology (In Detail)



Analysis

***Perf* = *f* (*PC*, *PE*, *SEC*, *AC*)**

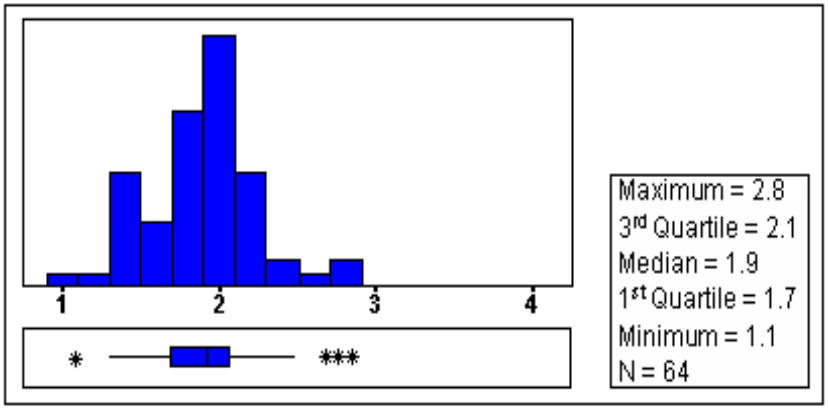
where: ***Perf*** = Project Performance
PE = Project Environment
SEC = Systems Engineering Capability
PC = Project Challenge
AC = Acquirer Capability

SEC can be further decomposed as:

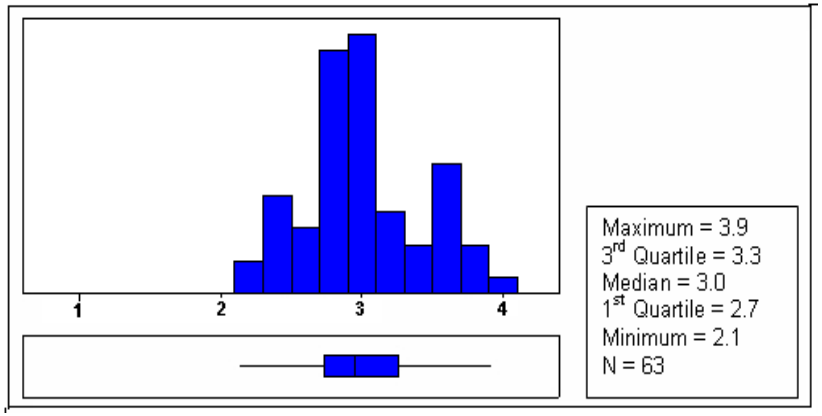
- Project Planning (SEC_{PP})
- Project Monitoring and Control (SEC_{PMC})
- Risk Management (SEC_{RSKM})
- Requirements Development and Management (SEC_{REQ})
- Technical Solution (SEC_{TS})
  - Trade Studies (SEC_{TRADE})
  - Product Architecture (SEC_{ARCH})
- Product Integration (SEC_{PI})
- Verification (SEC_{VER})
- Validation (SEC_{VAL})
- Configuration Management (SEC_{CM})
- IPT-Based Capability (SEC_{IPT})

SE capabilities and analyses are fully defined by mappings of associated survey question responses

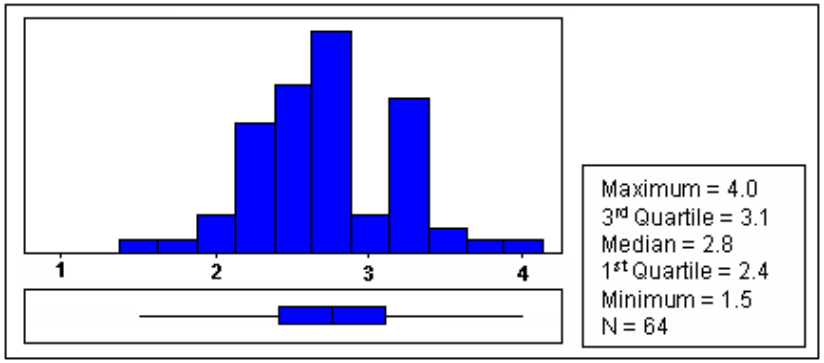
Analysis –
Characterization of Survey Responses



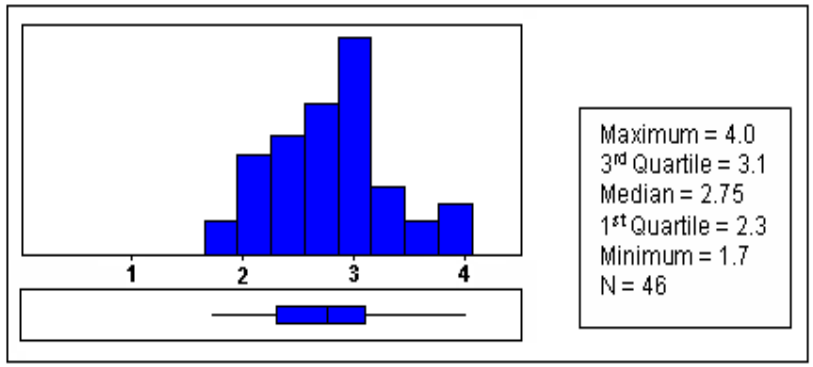
Project Challenge (PC)



Overall SE Capability (SEC)



Acquirer Capability (AC)

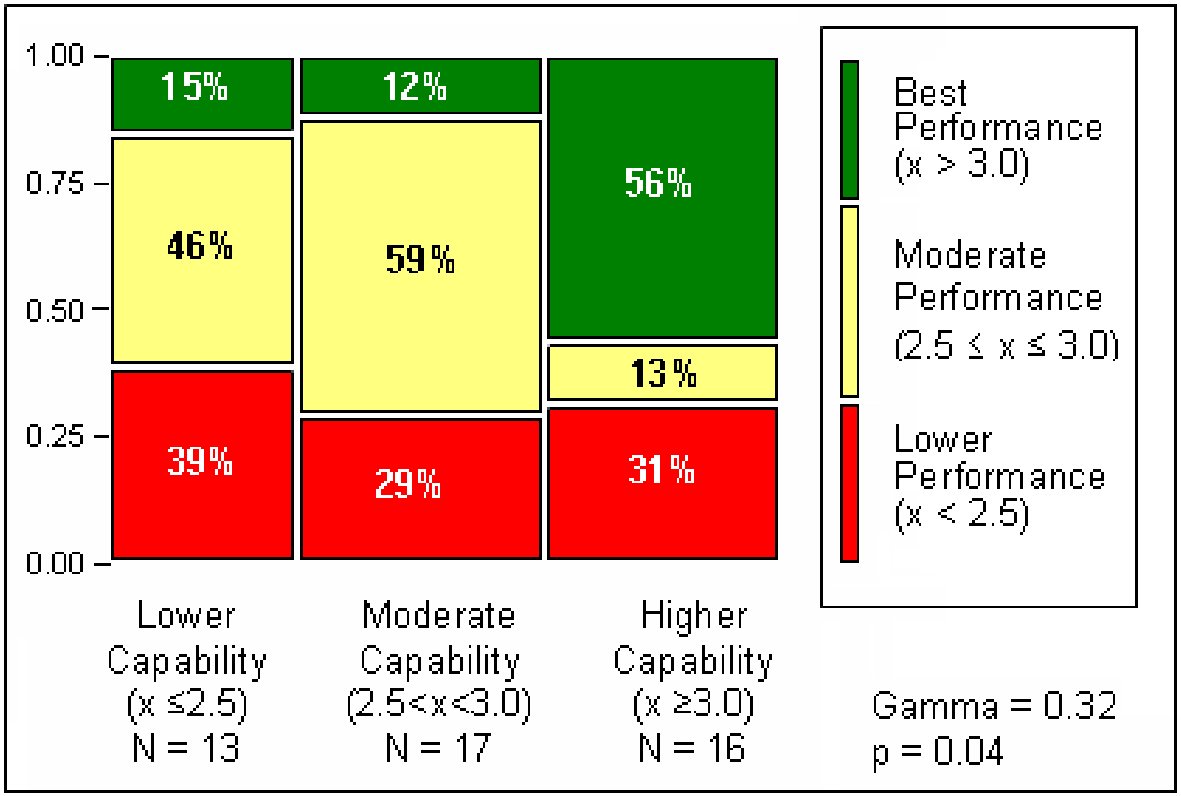


Project Performance (Perf)

Sufficient variation to support analysis

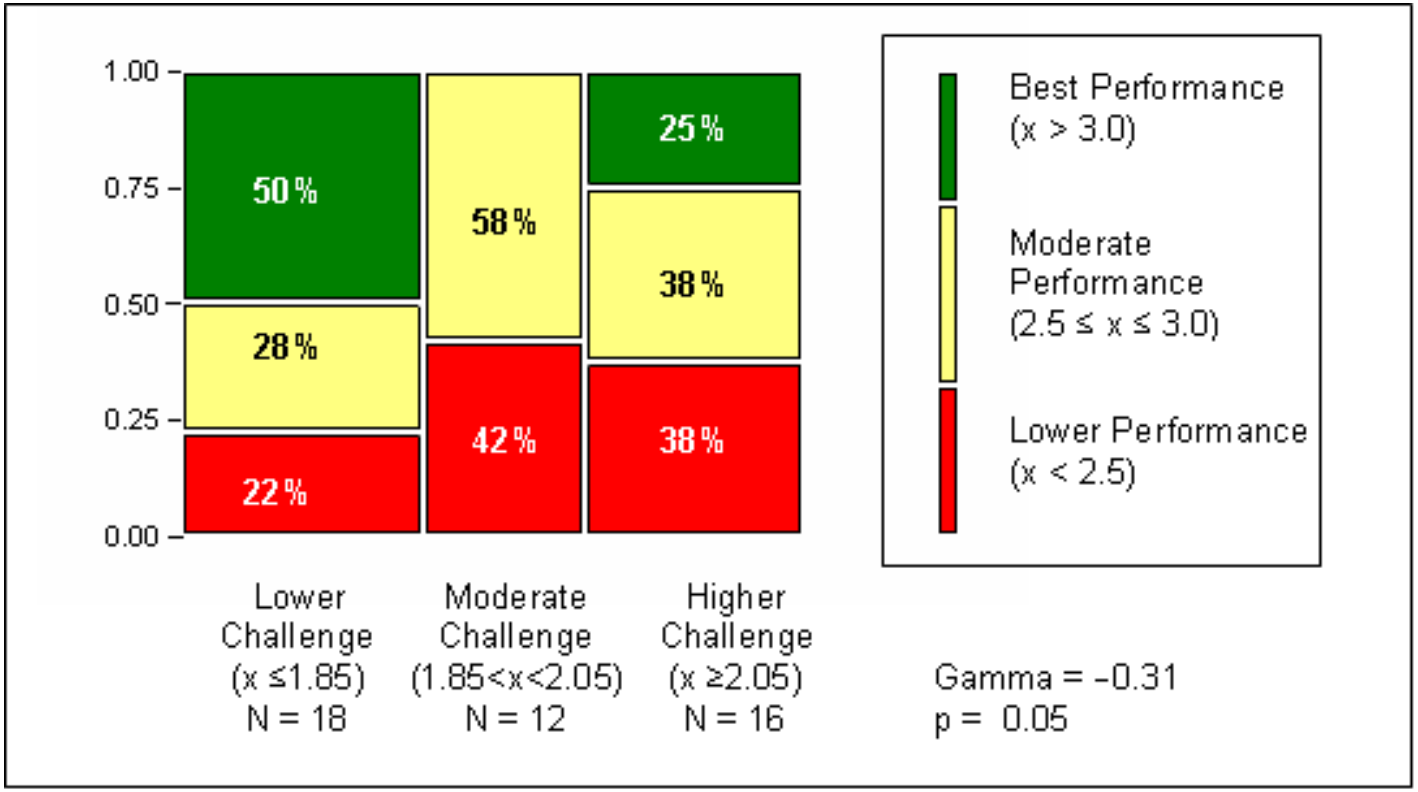
Total SE Capability (SEC) vs. Project Performance (Perf)

Notation



Projects with better Systems Engineering Capabilities deliver better Project Performance (cost, schedule, functionality)

Project Challenge (PC) vs. Project Performance (Perf)

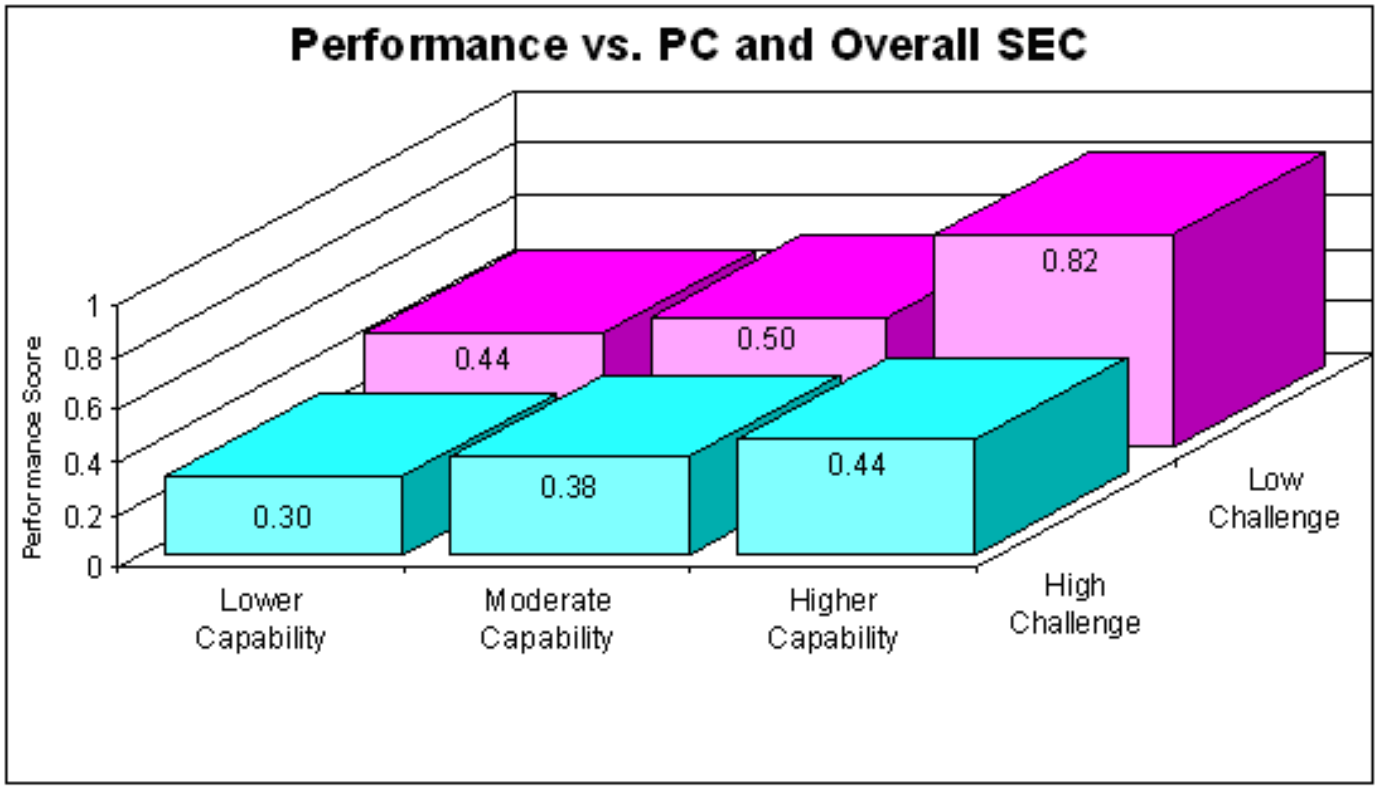


More Challenging Projects do not perform as well.

Relating Project Performance to Project Challenge and SE Capability

Project challenge factors:

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

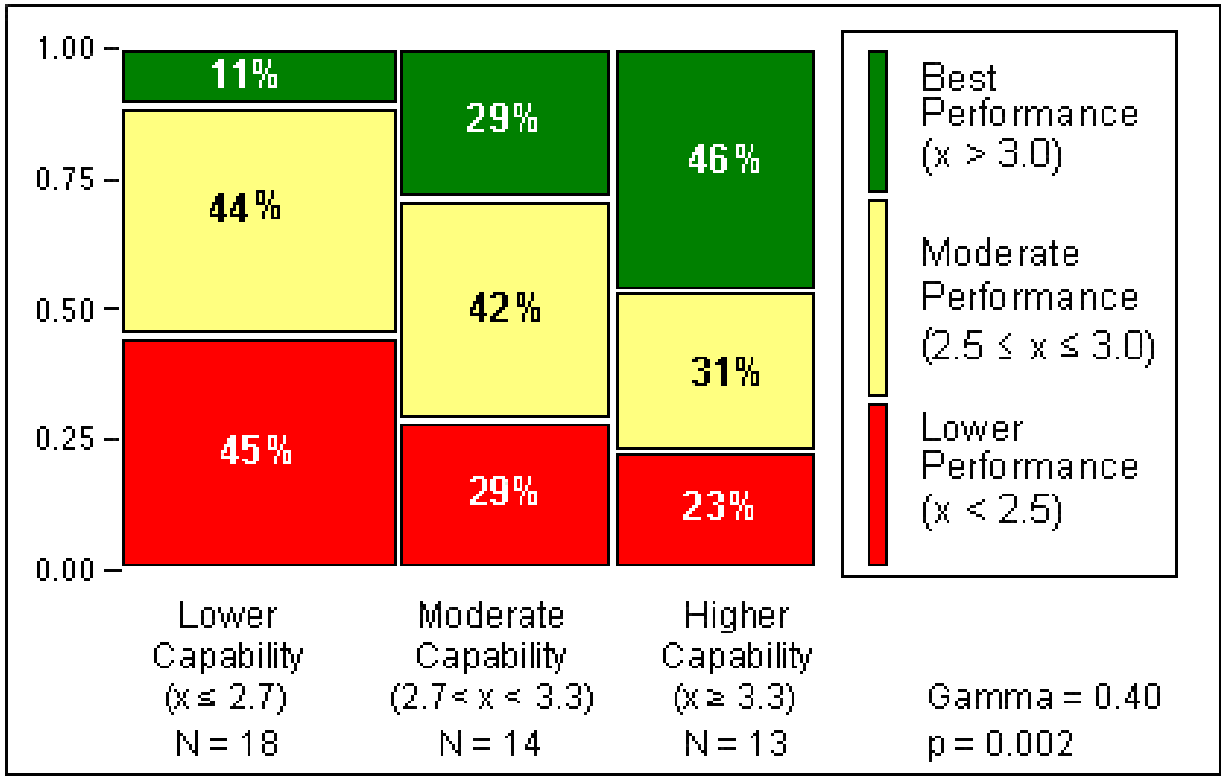


Projects with better Systems Engineering Capabilities are better able to overcome challenging environments

•Acquisition Support Program
•Joseph P. Elm

Results

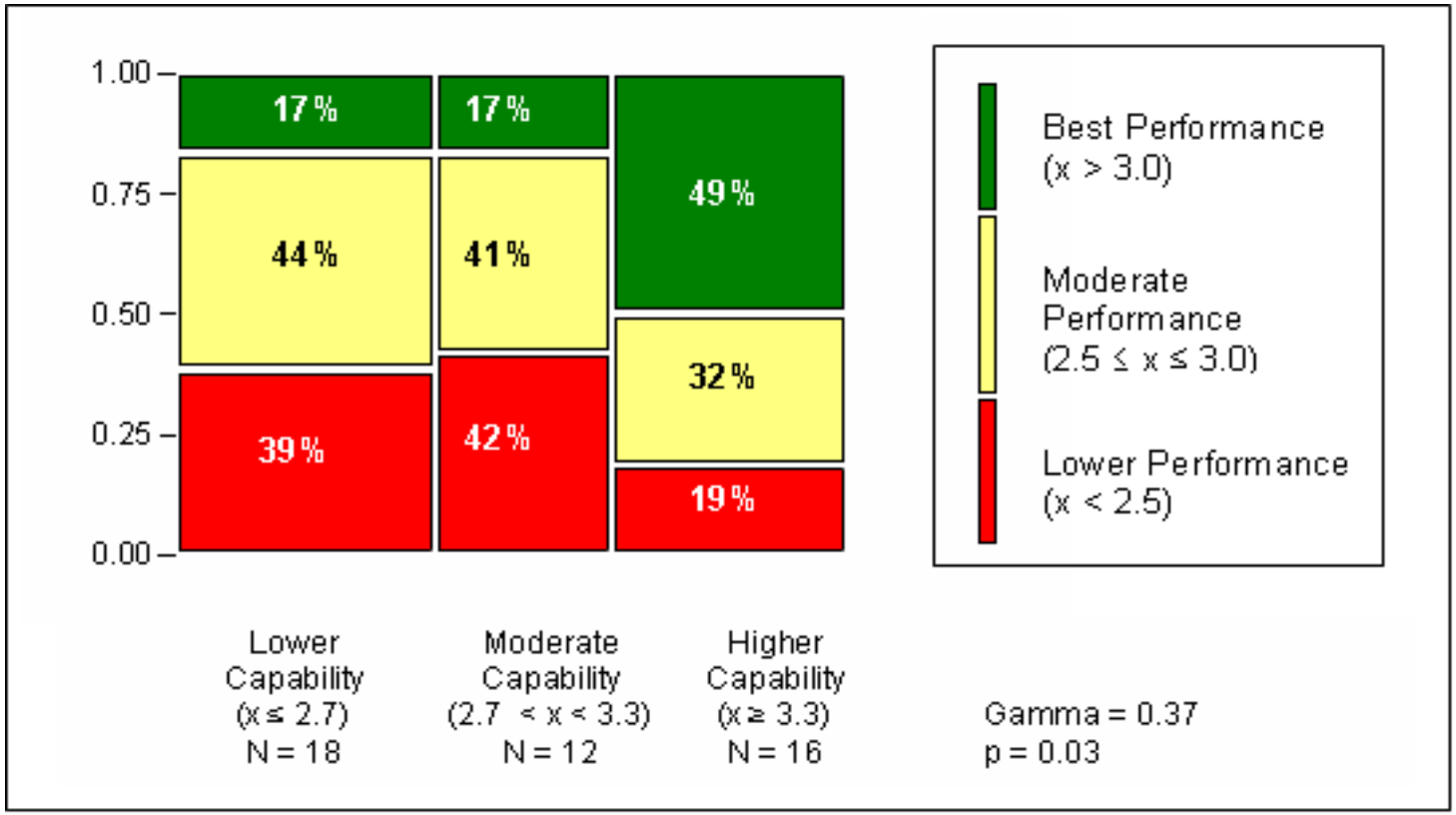
1. Product Architecture (SEC_{ARCH}) and Performance



Projects with better Product Architecture show a "Moderately Strong / Strong" Positive Relationship with Performance

Results

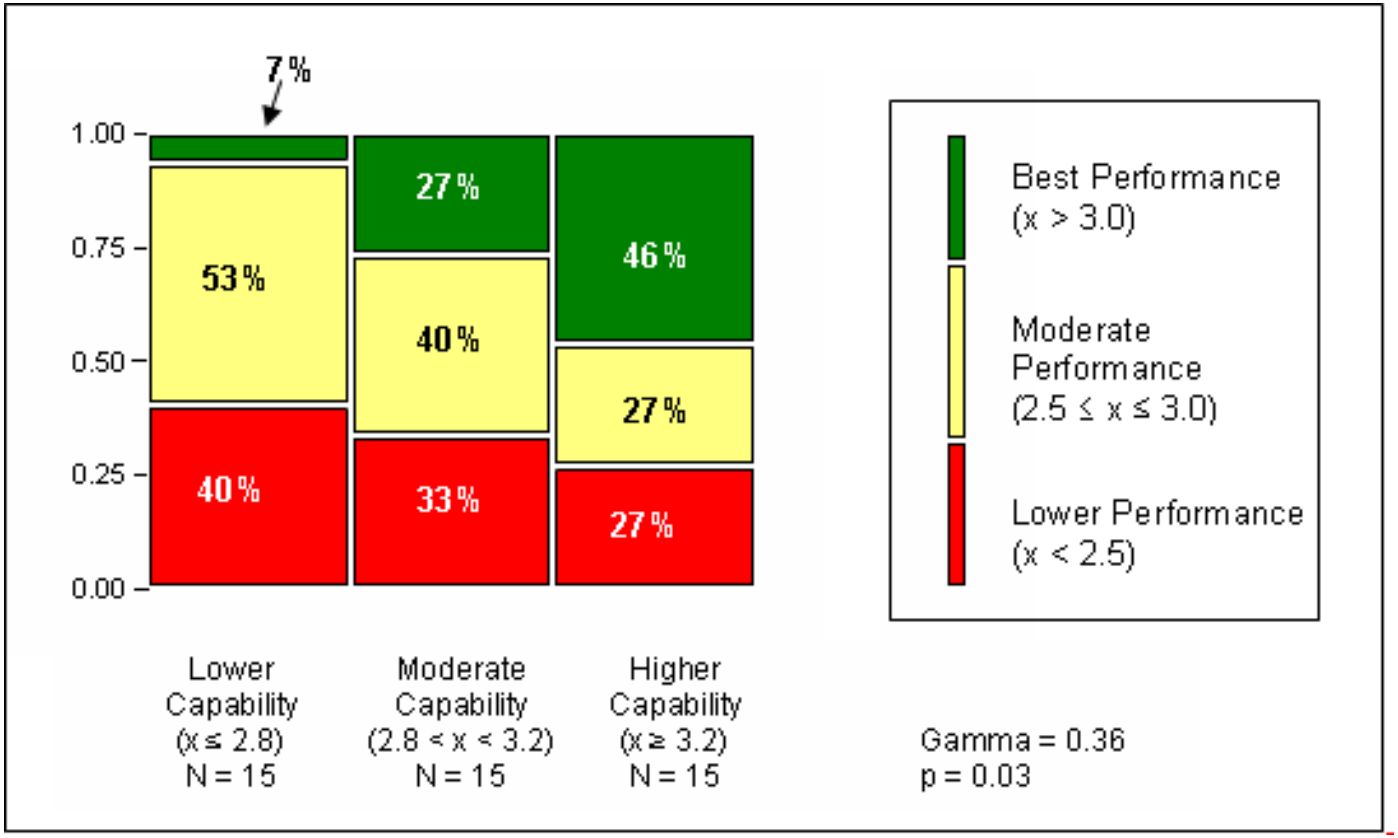
2. Trade Studies (SEC_{TRADE}) and Project Performance



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

Results

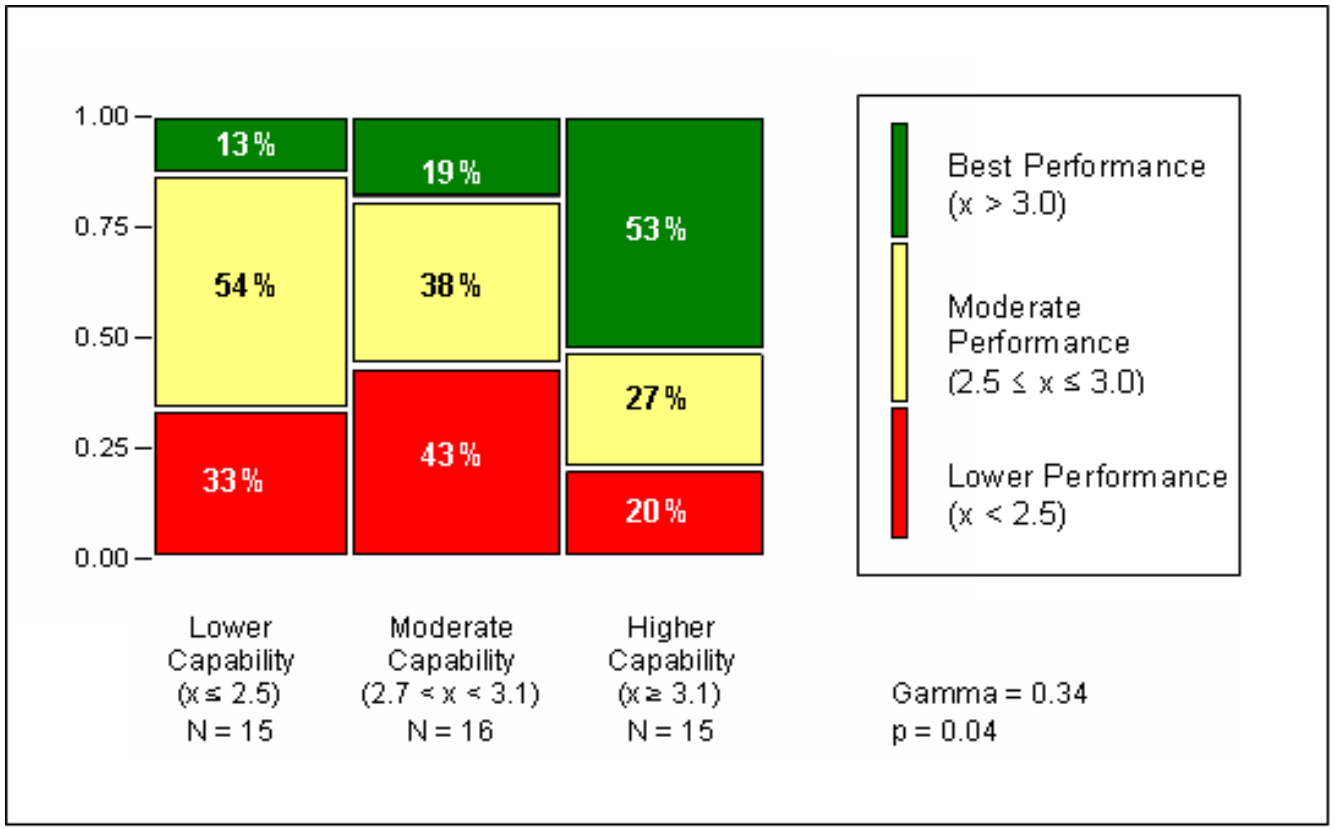
3. Technical Solution (SEC_{TS}) and Project Performance



Projects with better Technical Solution show a "Moderately Strong" Positive Relationship with Performance

Results

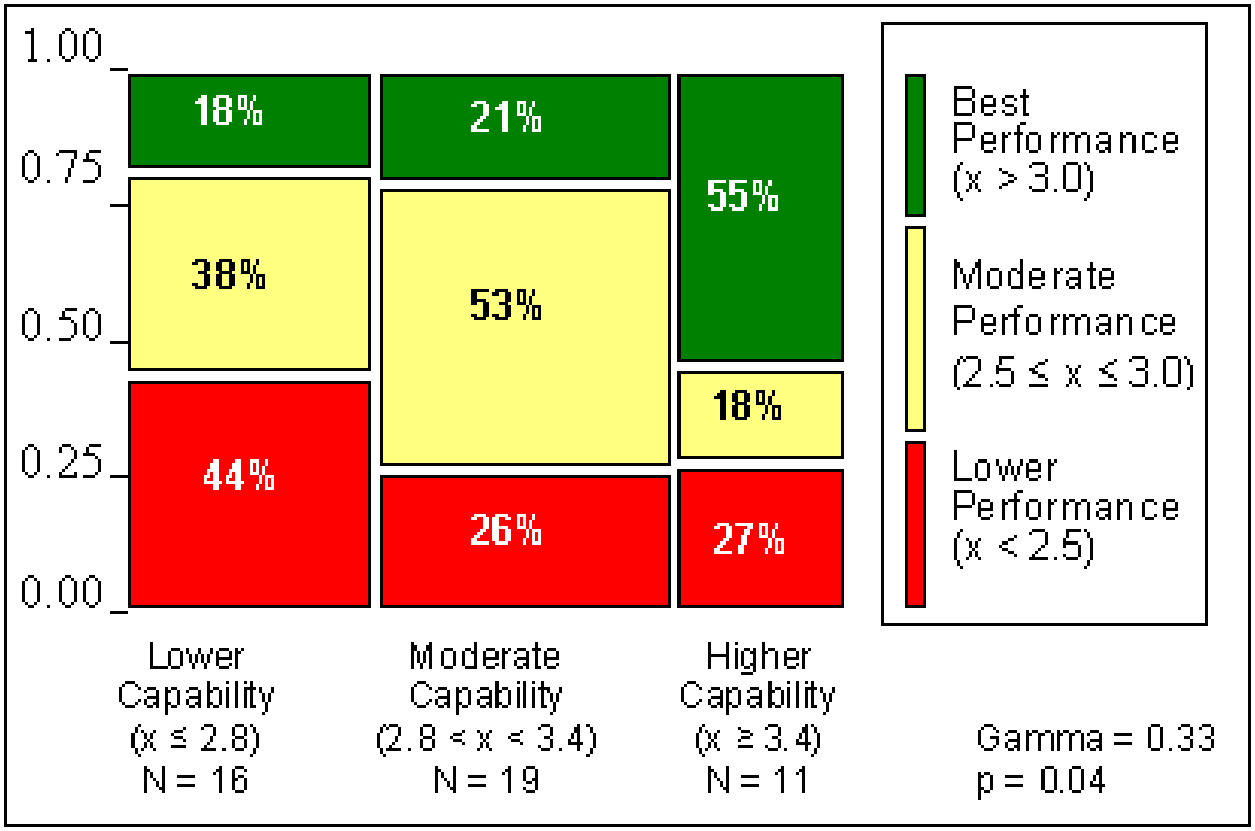
4. IPT-Related Capability (SEC_{IPT}) and Performance



Projects with better IPTs show a "Moderately Strong" Positive Relationship with Performance

Results

5. Requirements (SEC_{REQ}) and Performance

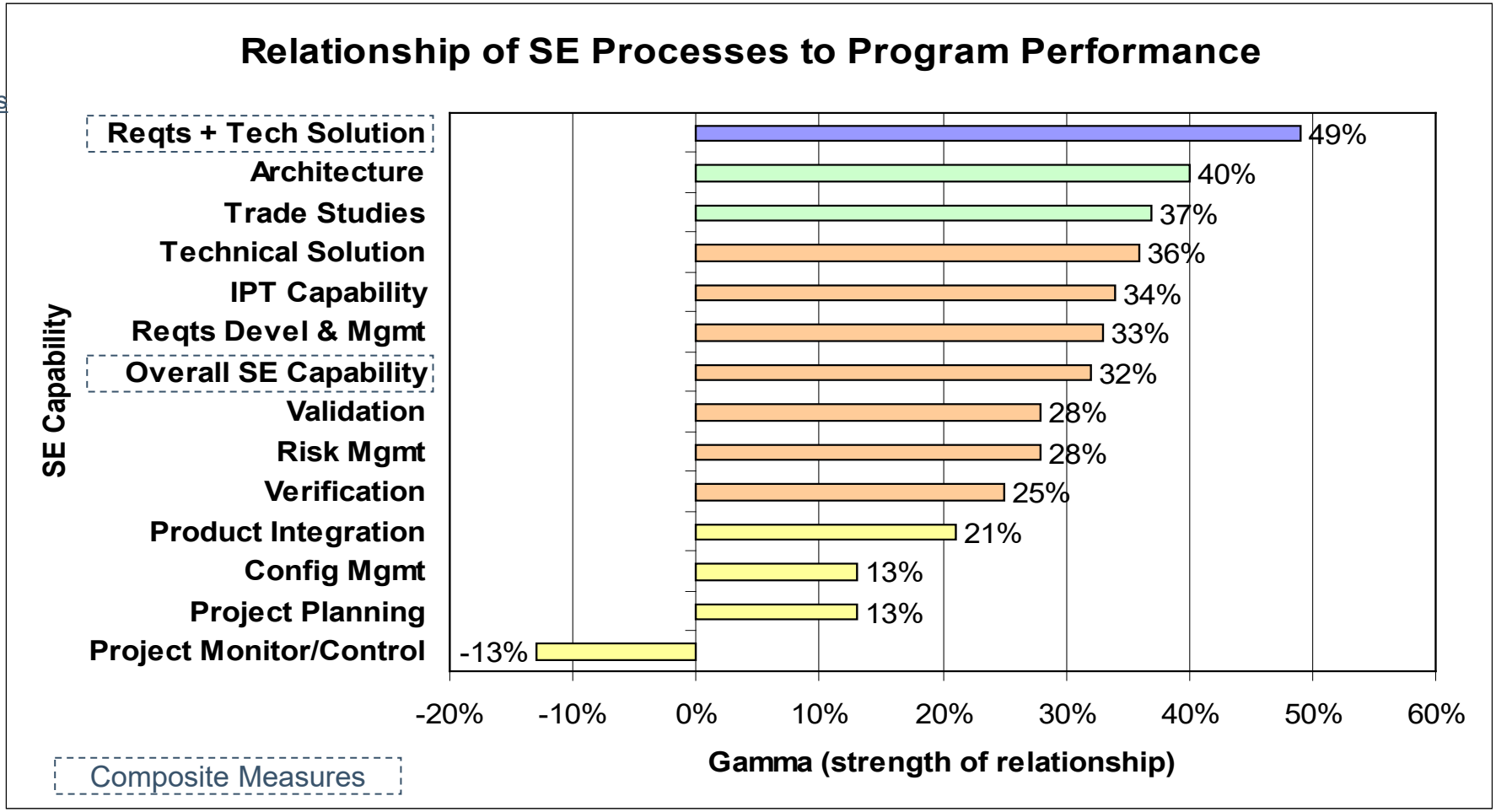


Projects with better Requirements Development and Management show a "Moderately Strong" Positive Relationship with Performance

Results

Summary of Relationships

Details



Strong Relationship

Moderately Strong to Strong Relationship

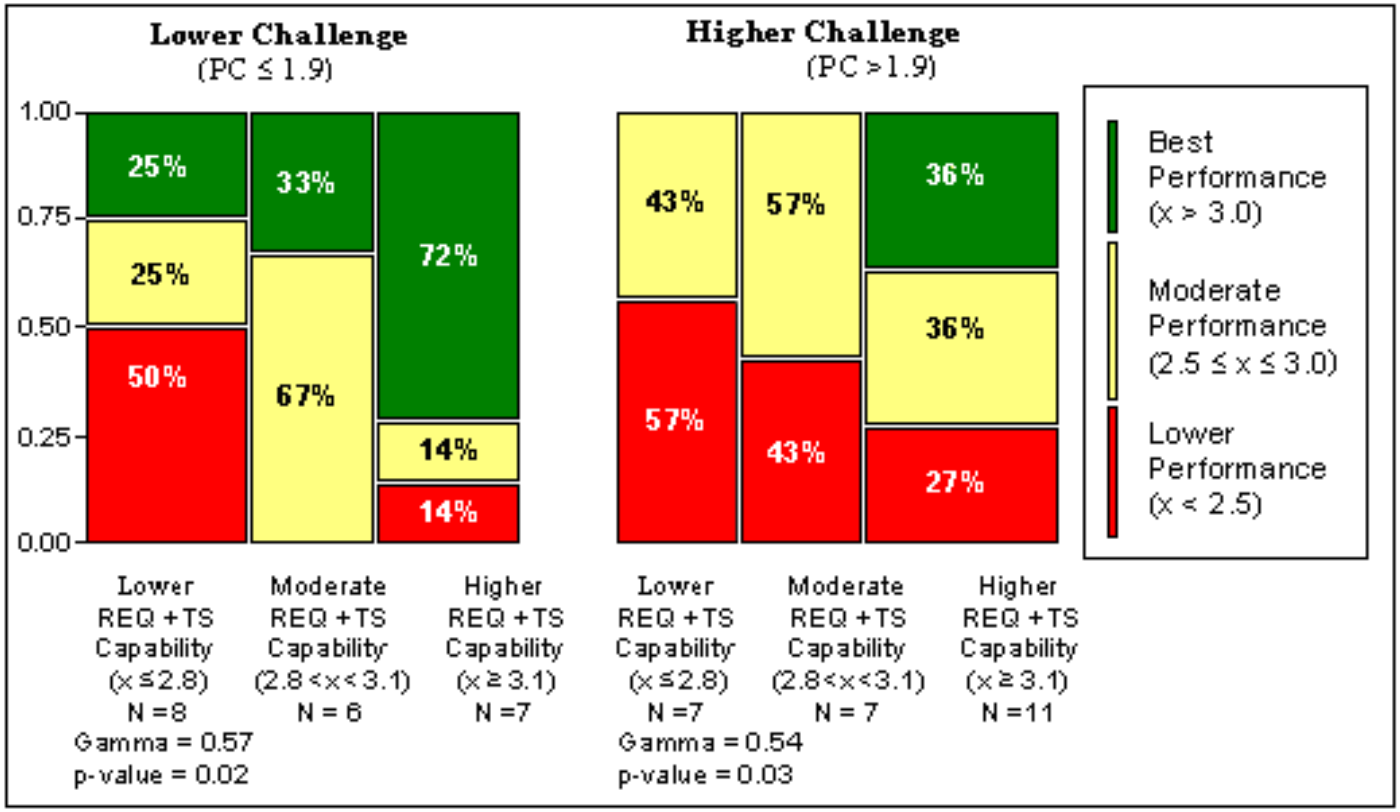
Moderately Strong Relationship

Weak Relationship

Results - Reqts + Tech Solution (SEC_{R+TS}) controlled by Project Challenge

Project challenge factors:

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



Value of the Research

Provide guidance for defense contractors in **planning capability improvement efforts**

Establish an **SE Capability Benchmark** for defense contractors

Provide **justification** and defense of defense contractor **SE investments**

Provide **guidance for acquirer evaluations** and source selections

Provide **guidance for contract monitoring**

Provide recommendations to OSD for areas to **prioritize SE revitalization**

Potential Next Steps

Additional analysis of collected data

Periodic repeat of the survey

Survey of system acquirers

Acknowledgements

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The report, "**A Survey of Systems Engineering Effectiveness**" is available at:
http://www.sei.cmu.edu/publications/documents/07.reports/07sr014.html

Backup

NDIA SE Effectiveness Survey Analysis Slides

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

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
	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

	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																	
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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
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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
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%															36%	50%	4.0

Details

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

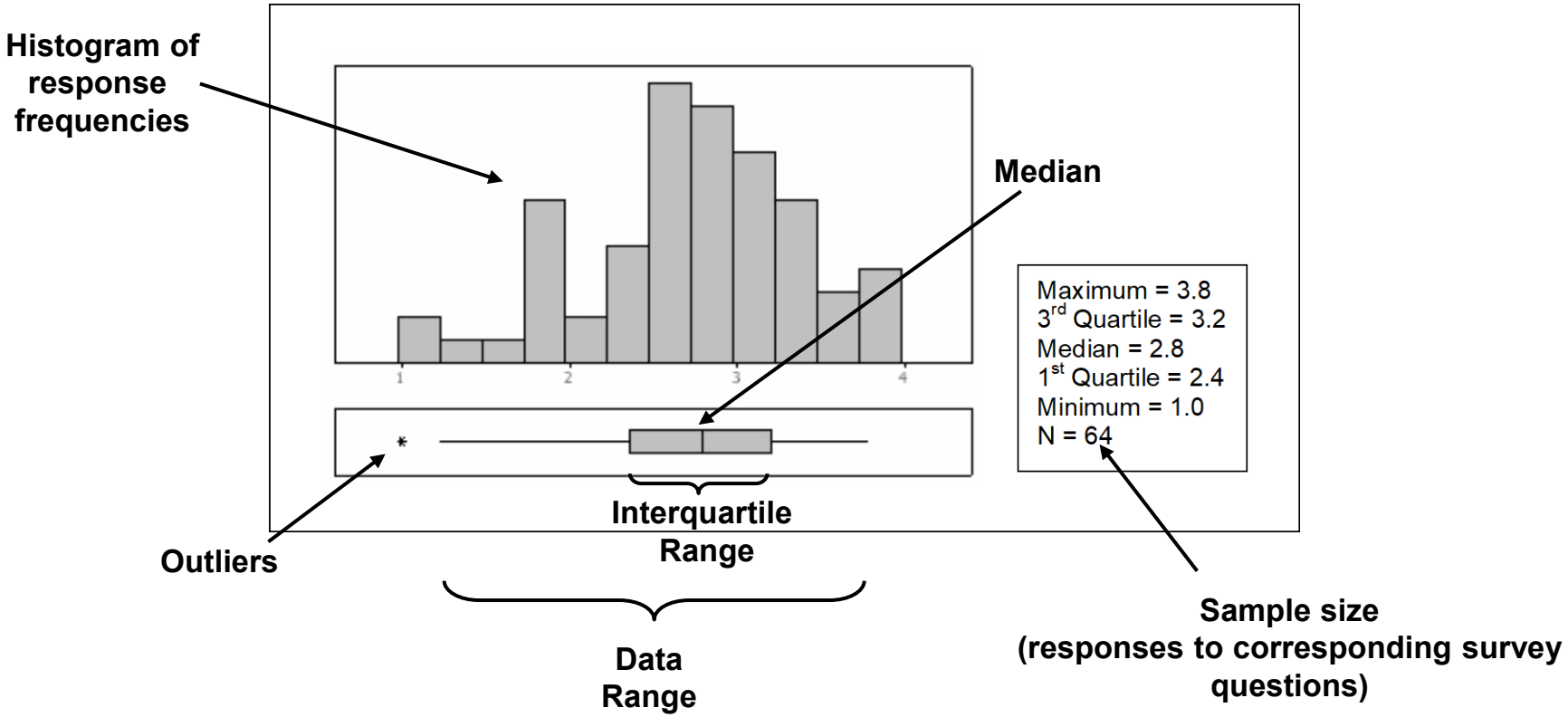
*Based on small partitioned sample size

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

probability
ly low

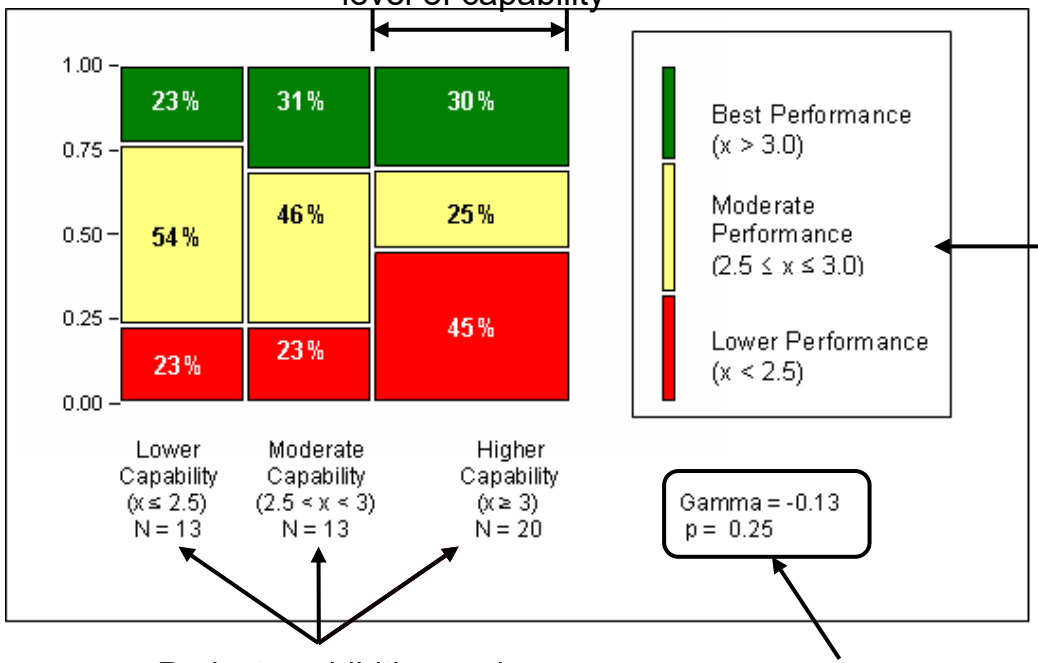
to strong

Terminology and Notation
Distribution Graph



Terminology and Notation
Mosaic Chart

Column width represents proportion of projects with this level of capability



Relative performance distribution of the sample

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

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

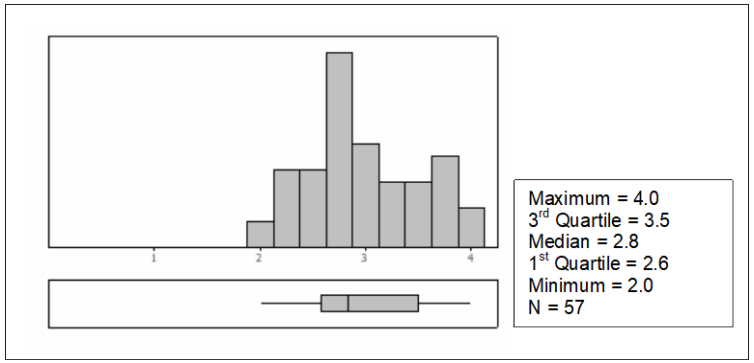
Measures of association and statistical test

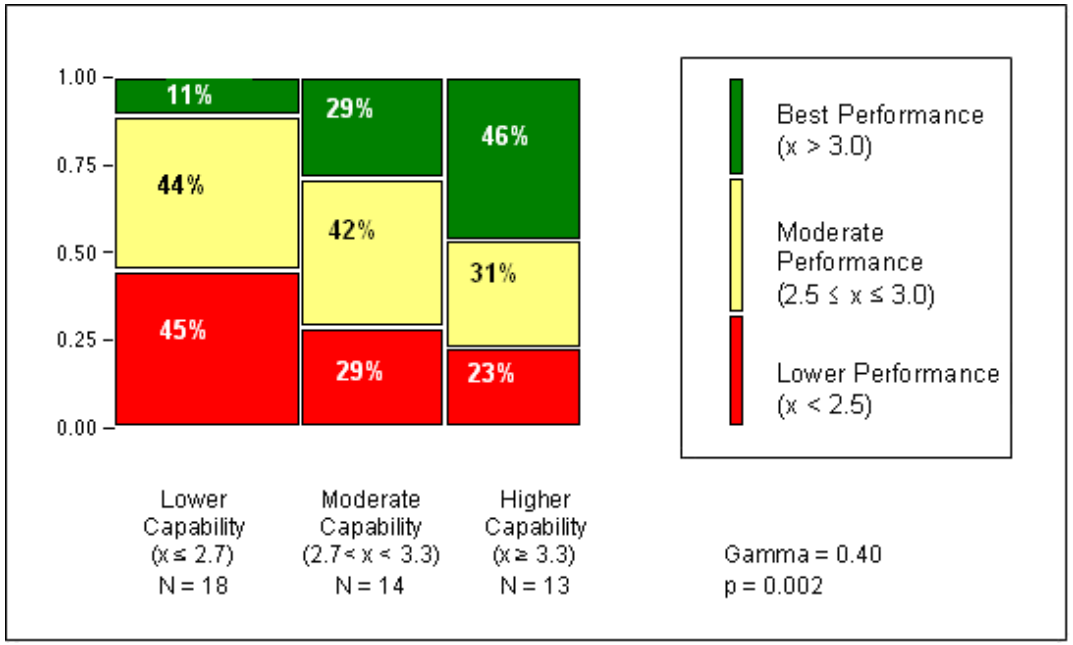
Gamma: measures strength of relationship between two ordinal variables

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

SE Capability:
Product Architecture (ARCH)

14 19 29





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)

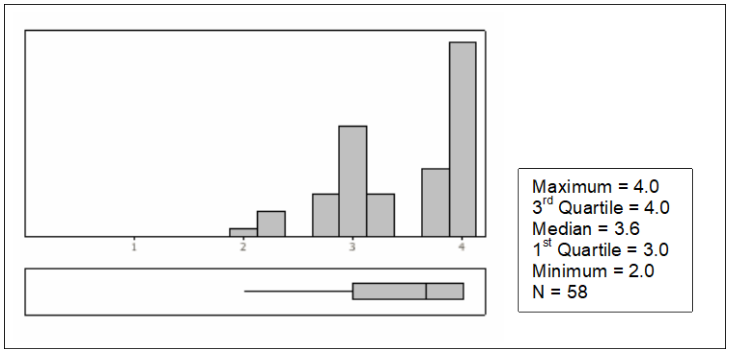
Survey Questions

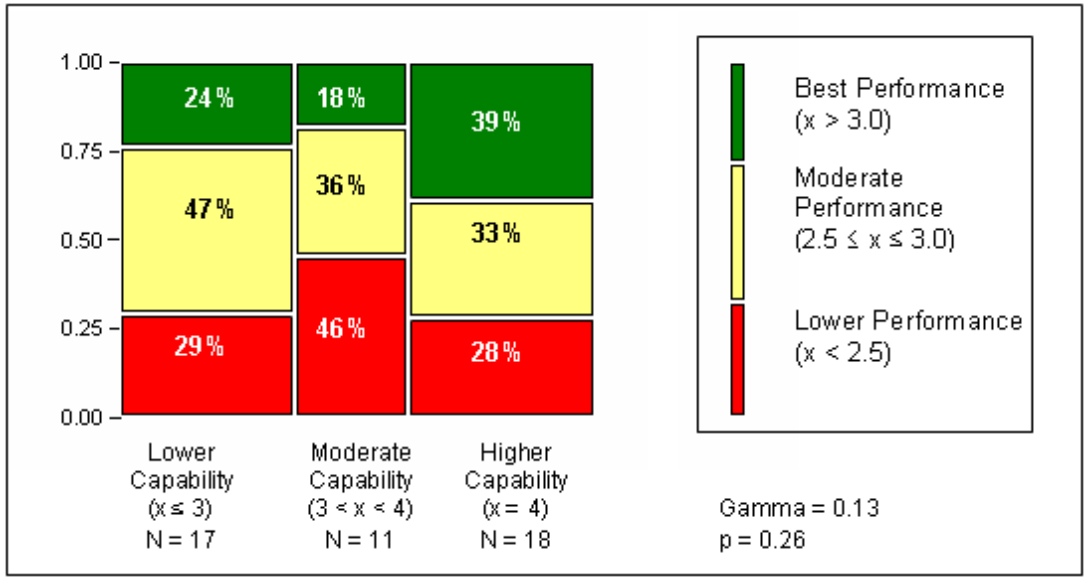
14 19 29

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)

19 29





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

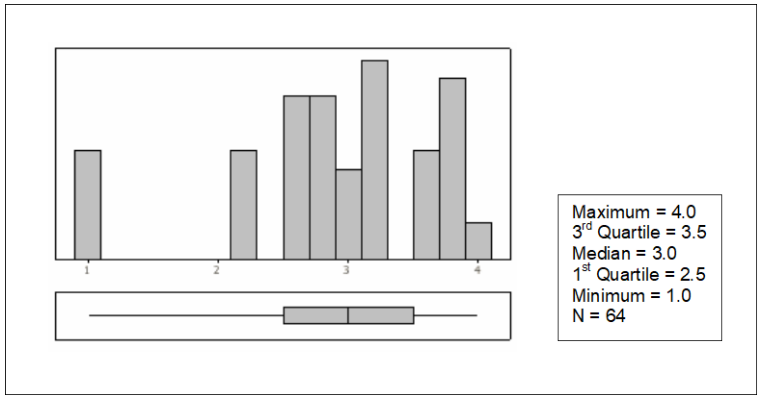
SE Capability:
Configuration Management (CM)

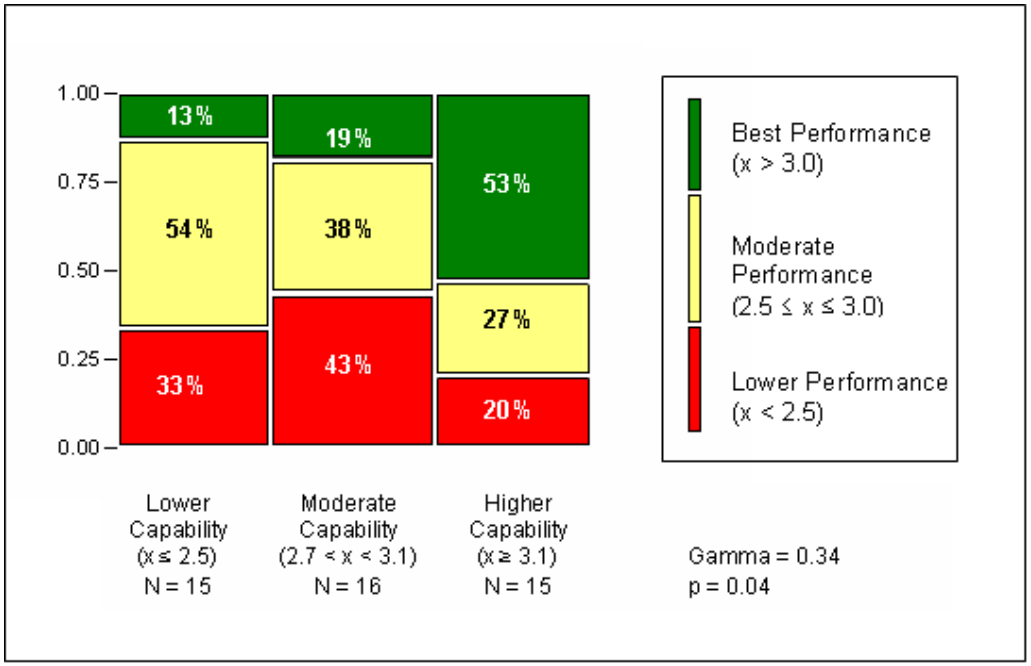
Survey Questions

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)

17 19 29





Relationship to project performance:	Moderately 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
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)

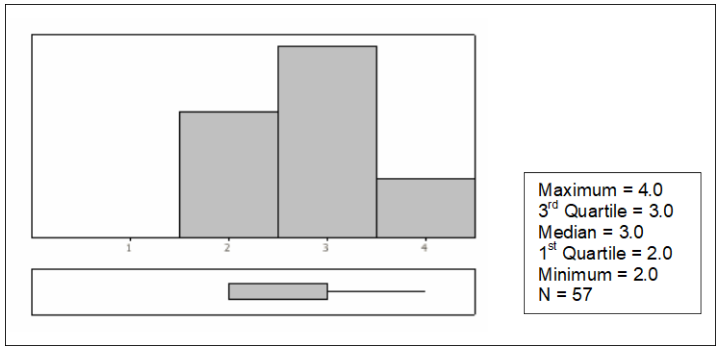
Survey Questions

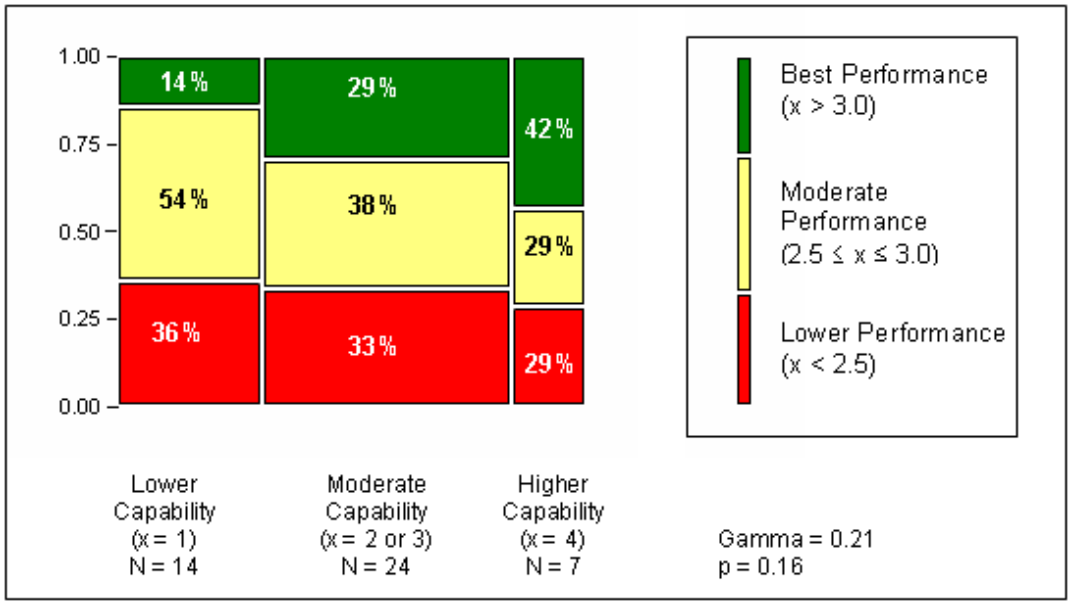
17 19 29

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)

19 29





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

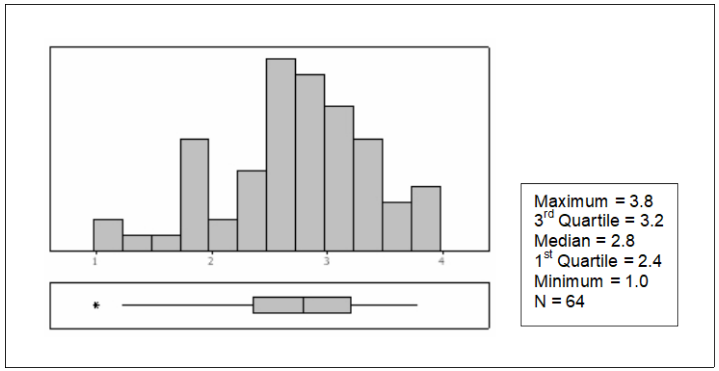
SE Capability:
Product Integration (PI)

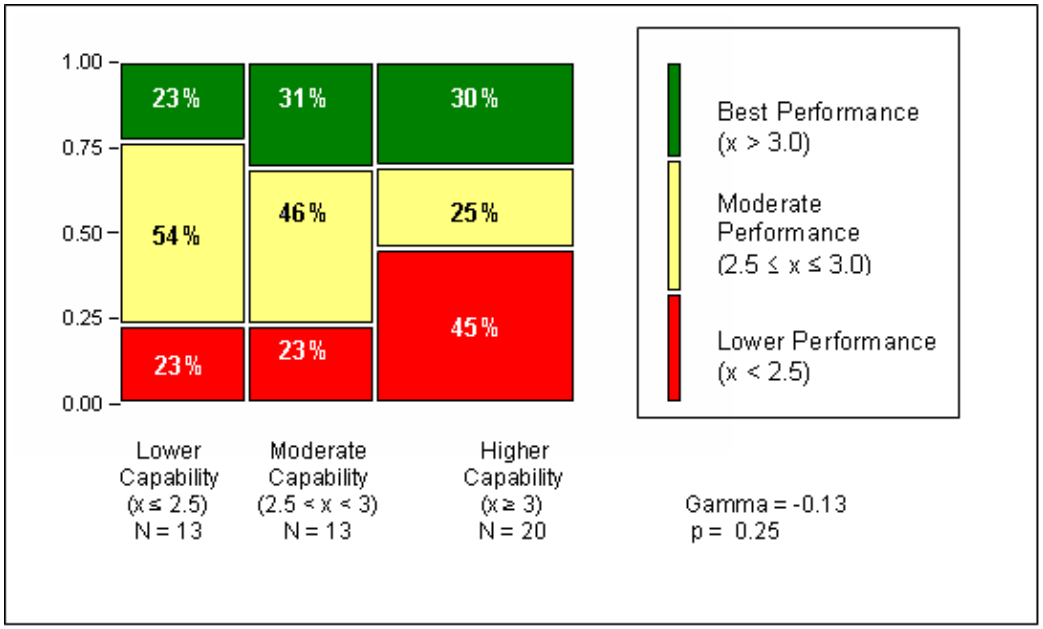
Survey Question

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)

19 29





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

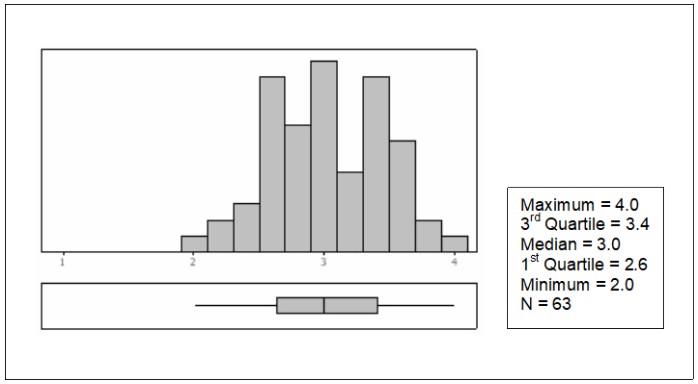
SE Capability:
Project Monitoring and Control (PMC)

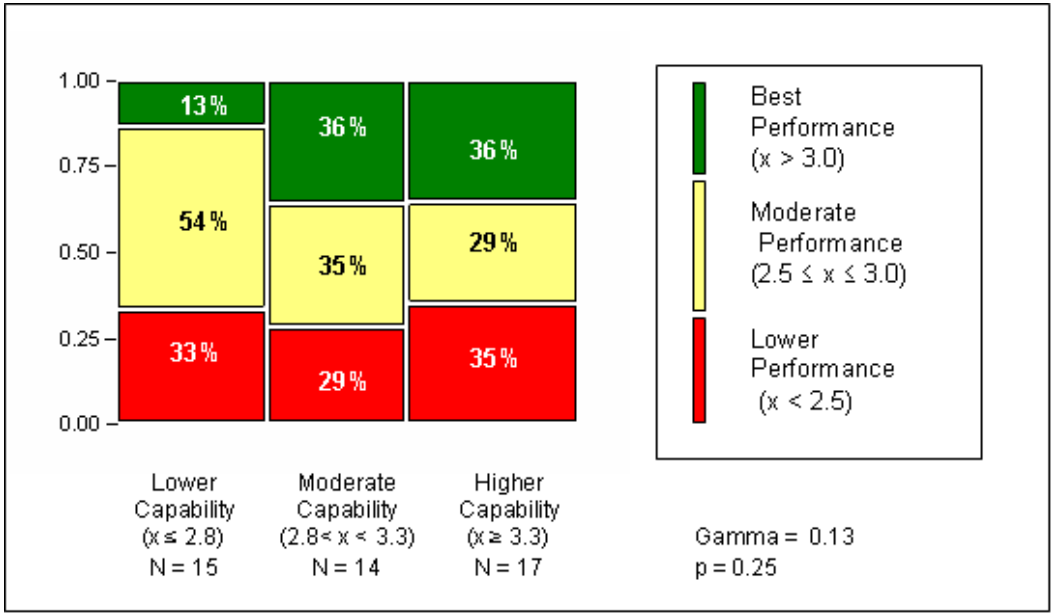
Survey Questions (Part 2)

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)

19 29





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

SE Capability:
Project Planning (PP)

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

SE Capability:
Project Planning (PP)

Survey Questions (Part 2)

ID	Question	Response range
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
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

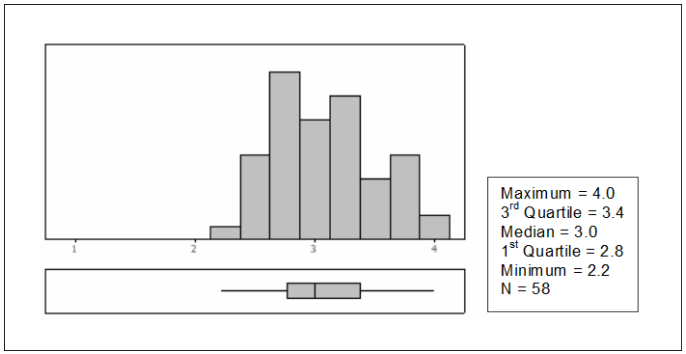
SE Capability:
Project Planning (PP)

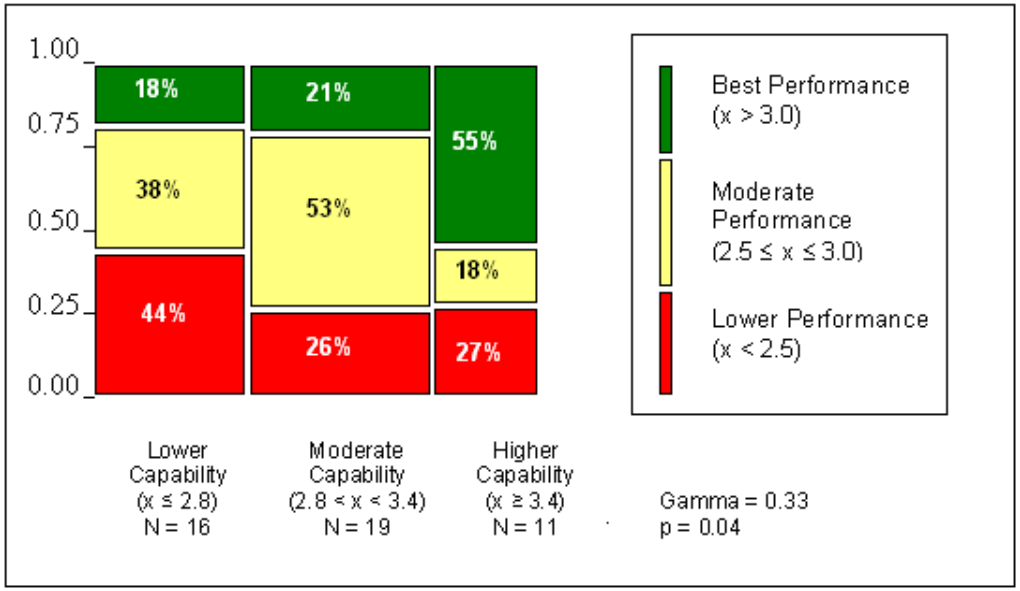
Survey Questions (Part 3)

ID	Question	Response range
PD05d	This project has an integrated event-based schedule that is consistent with the WBS	•strongly disagree •disagree •agree •strongly agree
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)

18 19 29





Relationship to project performance:	Moderately 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	33%	4.0%	1.0	44%	38%	18%	2.8	2.8	26%	53%	21%	3.4	3.4	27%	18%	55%	4.0

SE Capability:
Requirements Development & Mgmt (REQ)

Survey Questions (Part 1)

18 19 29

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

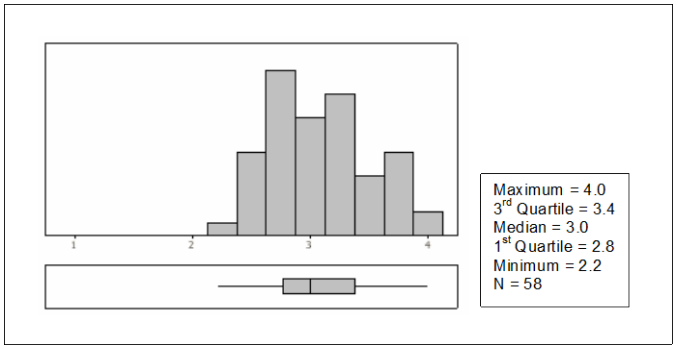
SE Capability: Requirements Development & Mgmt (REQ)

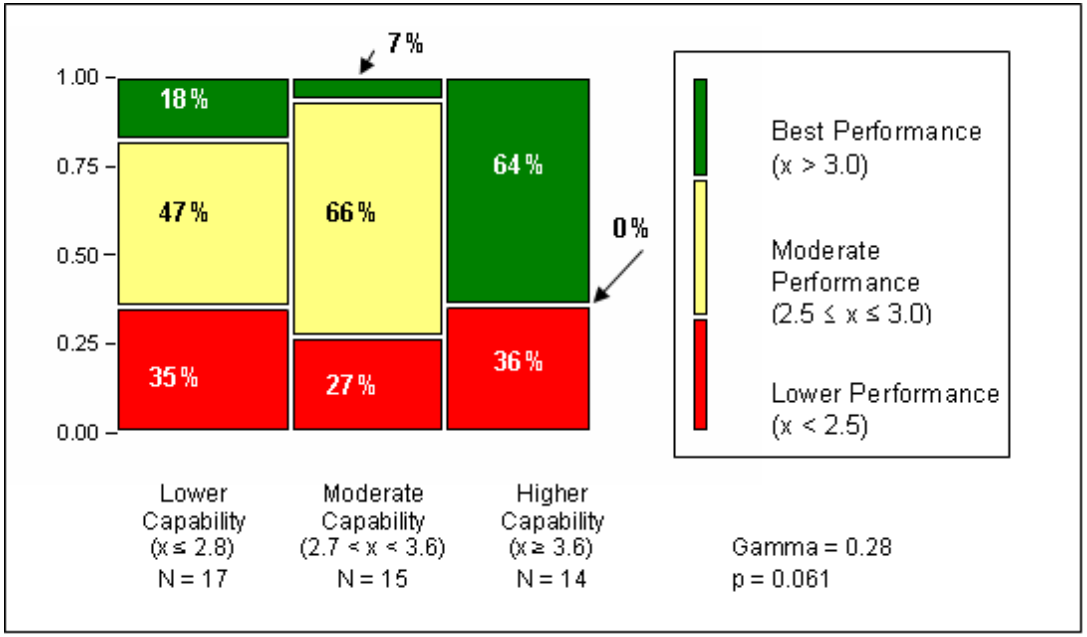
Survey Questions (Part 2)

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)

19 29





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

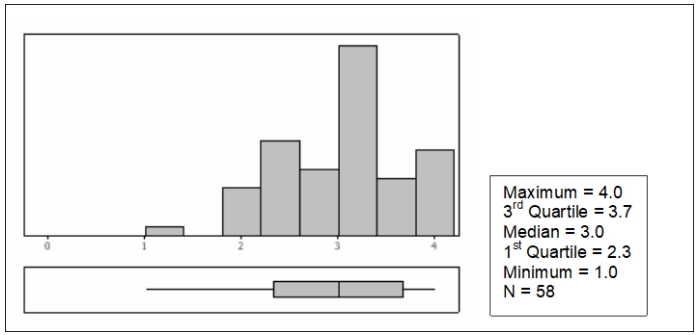
SE Capability:
Risk Management (RSKM)

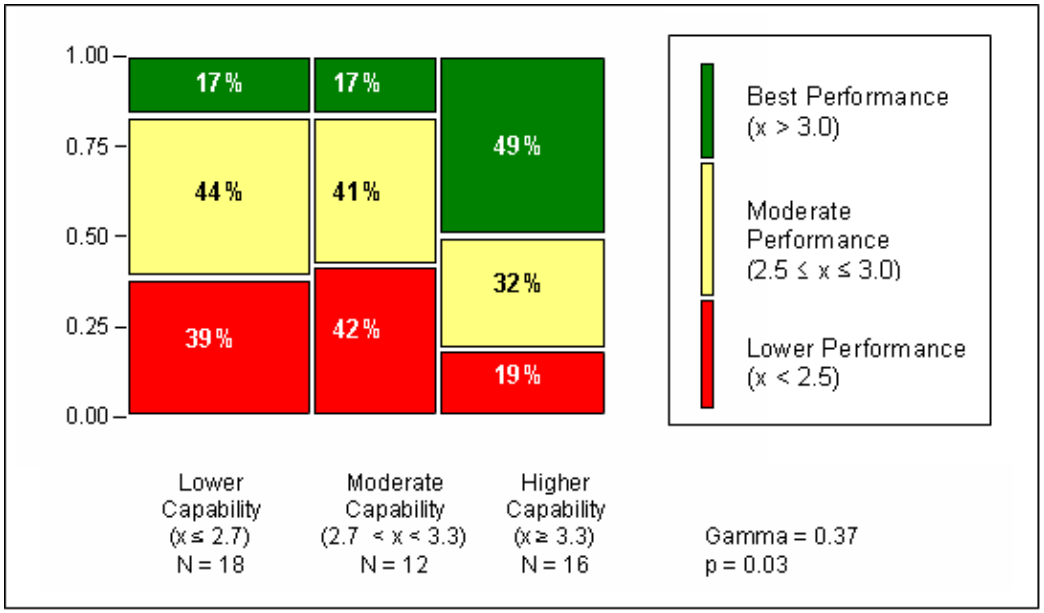
Survey Questions

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)

15 19 29





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)

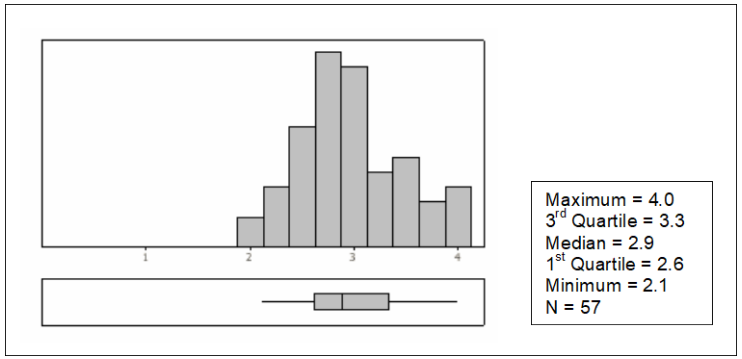
Survey Questions

15 19 29

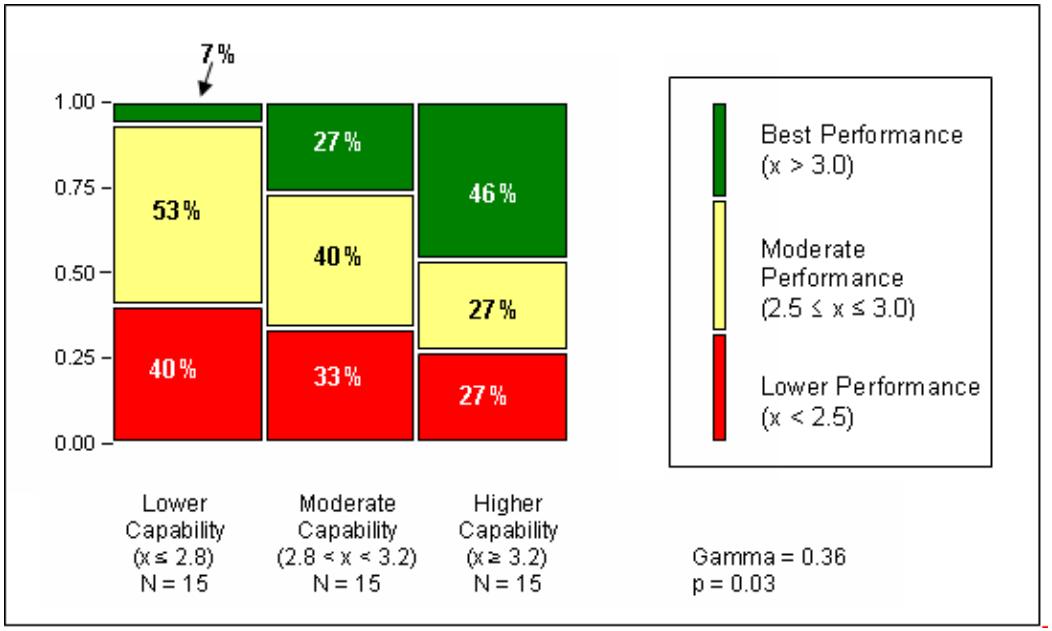
ID	Question	Response range
RD11	Stakeholders impacted by trade studies are involved in the development and performance of those trade studies	•strongly disagree •disagree •agree •strongly agree
RD12	This project performs and documents trade studies between alternate solutions based upon definitive and 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)

16 19 29



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

SE Capability:
Technical Solution (TS)

Survey Questions (Part 1)

16 19 29

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

SE Capability:
Technical Solution (TS)

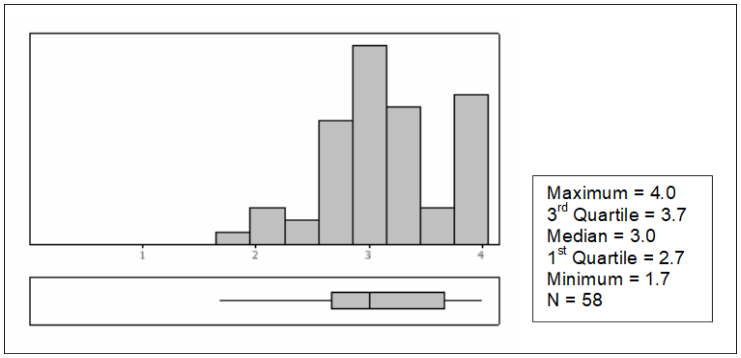
Survey Questions (Part 2)

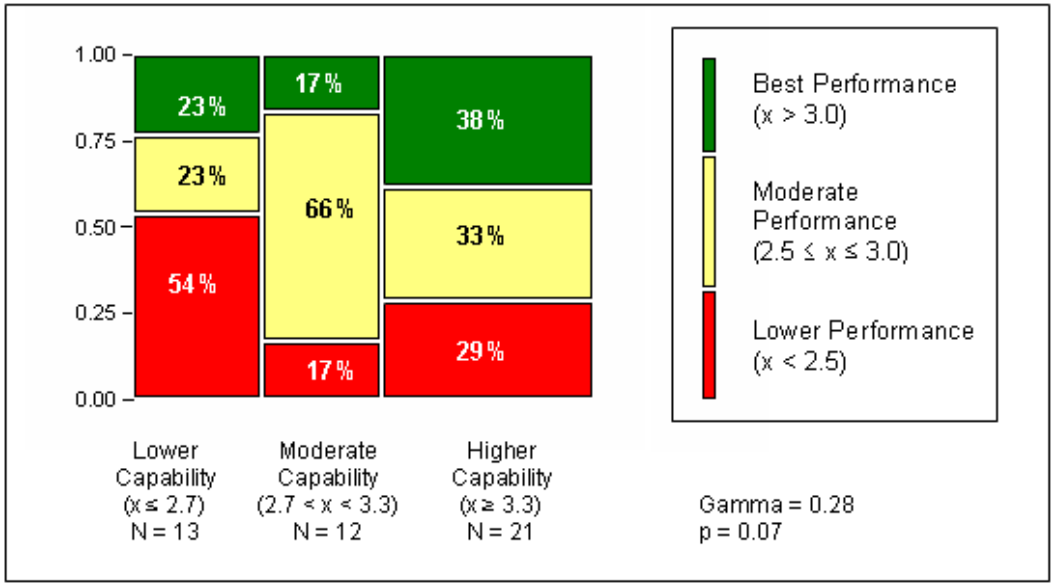
16 19 29

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)

19 29





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

SE Capability:
Validation (VAL)

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)

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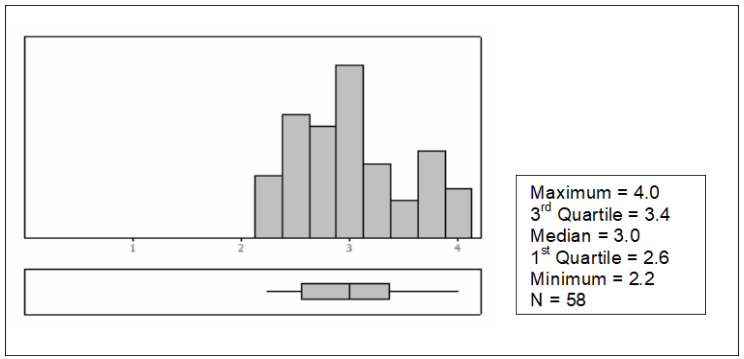

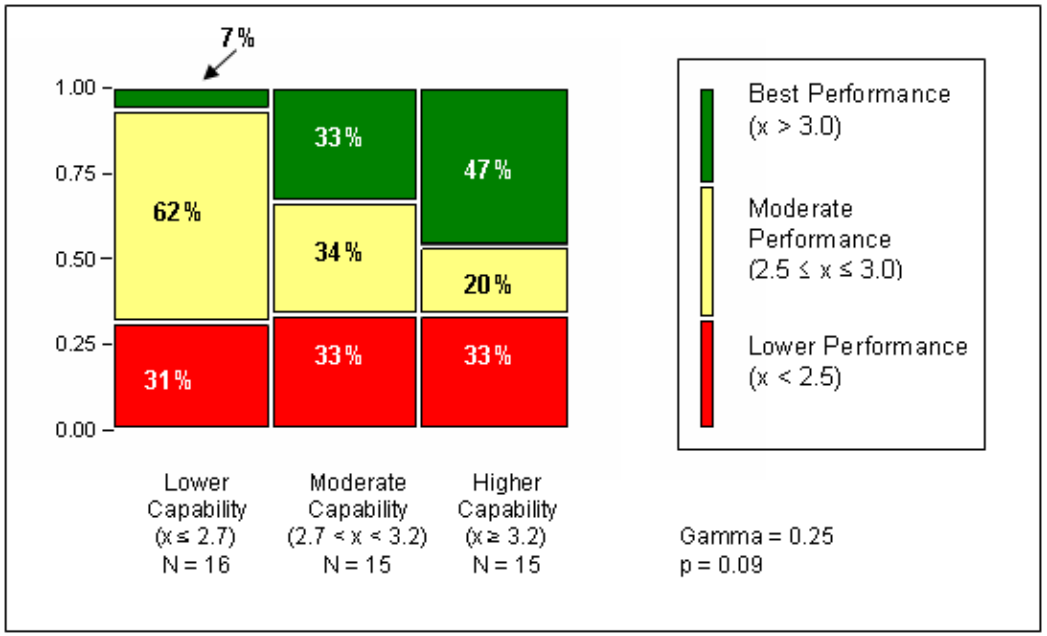

Relationship to project performance:	Moderately strong positive relationship

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

SE Capability:
Verification (VER)

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

SE Capability:
Verification (VER)

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)

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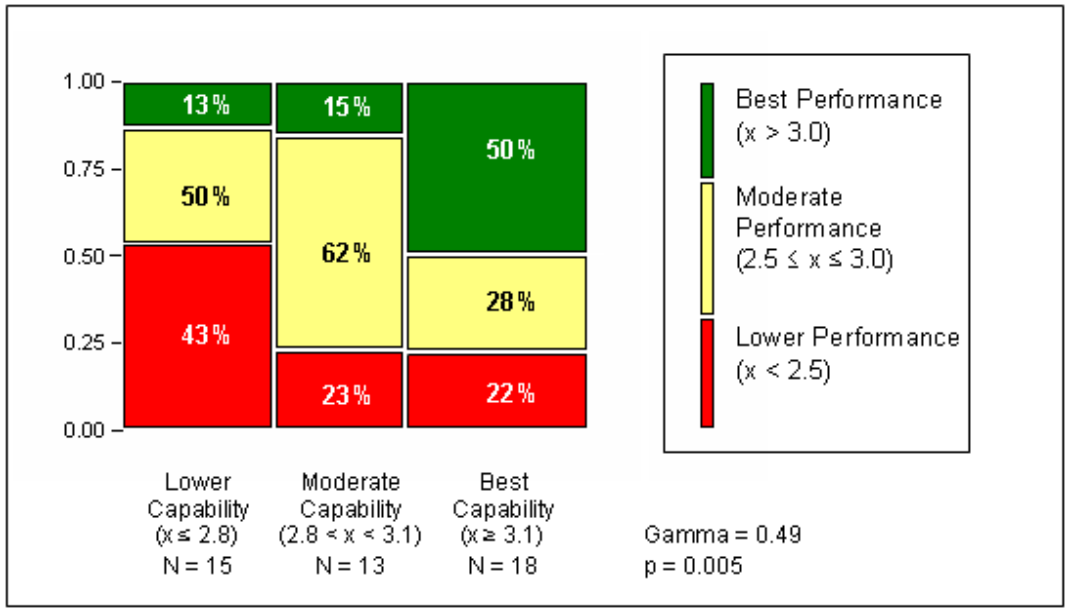
(This is a higher order measure; see base measures for distribution)



Relationship to project performance:	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+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

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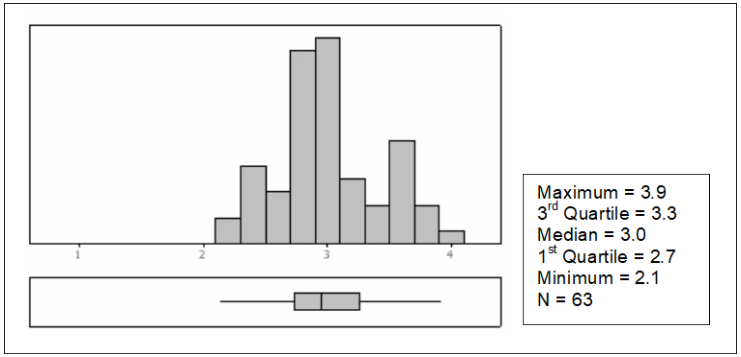

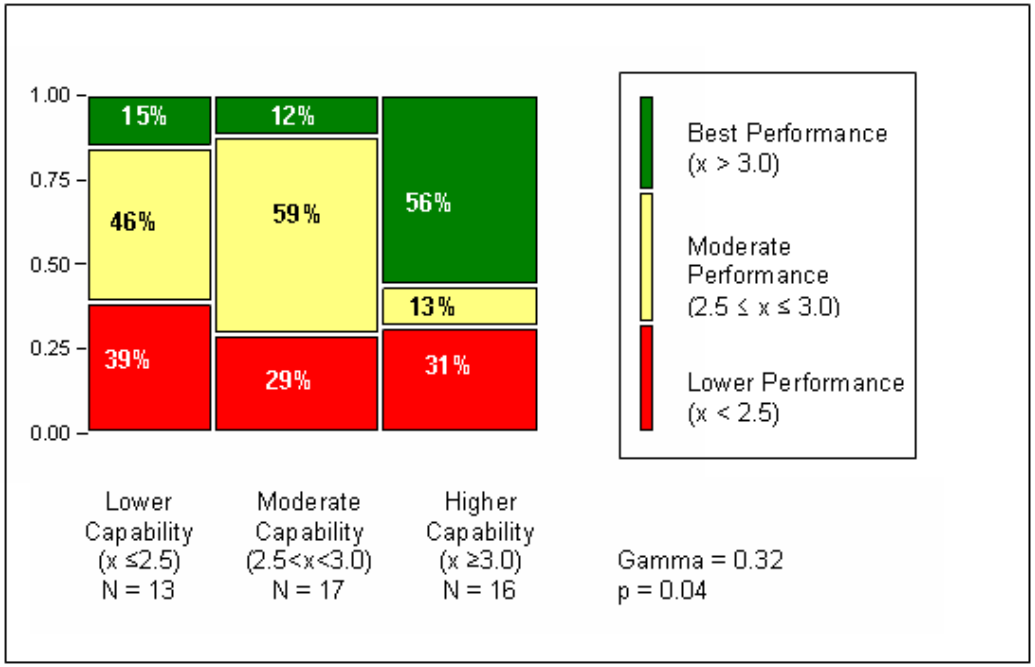

Relationship to project performance:	Moderately strong positive relationship

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
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)

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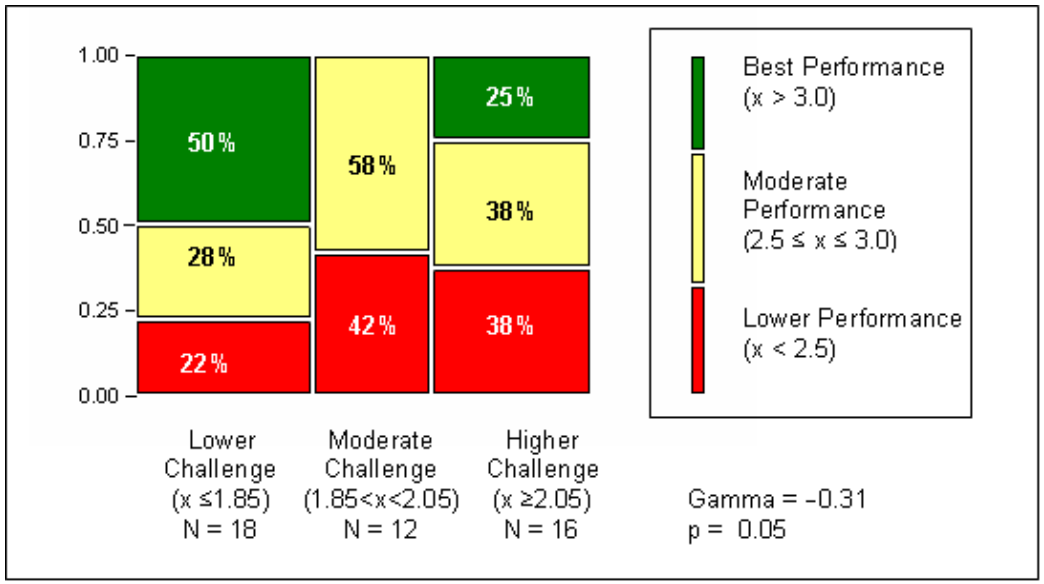
Project challenge factors:

- **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

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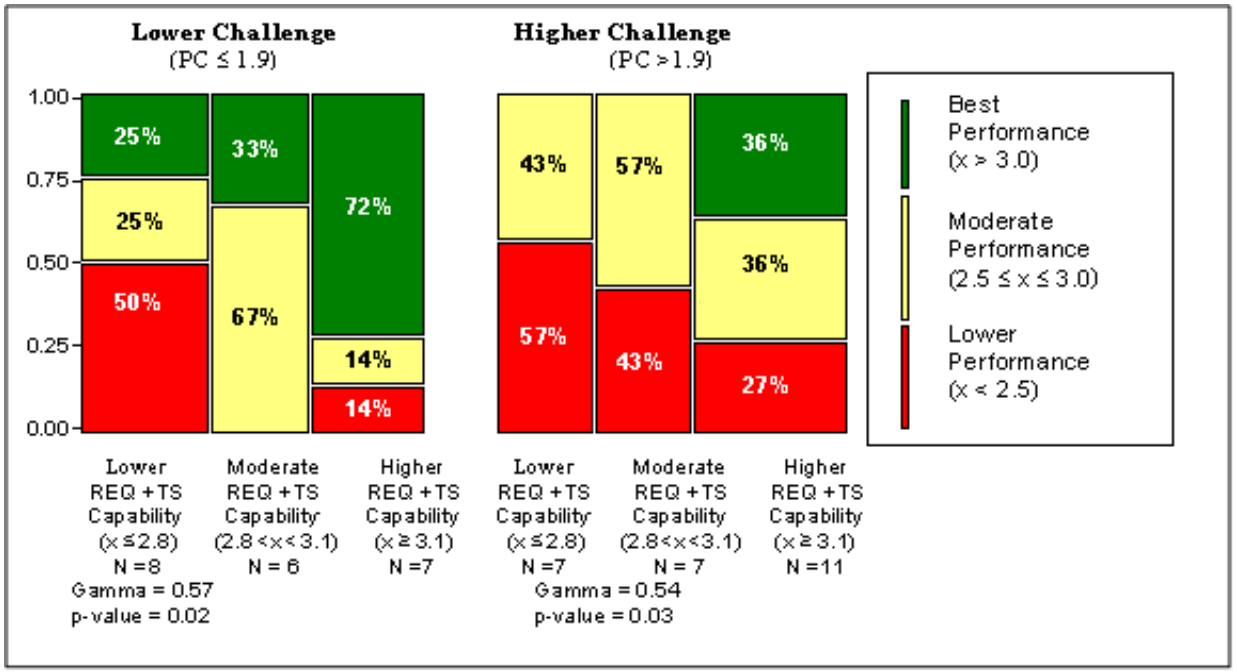
Project challenge factors:
- Life cycle phases
- Project characteristics
  (e.g., size, effort, duration, volatility)
- Technical complexity
- Teaming relationships



Relationship to project performance:	Very strong positive relationship

SE Capability + Project Challenge

	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+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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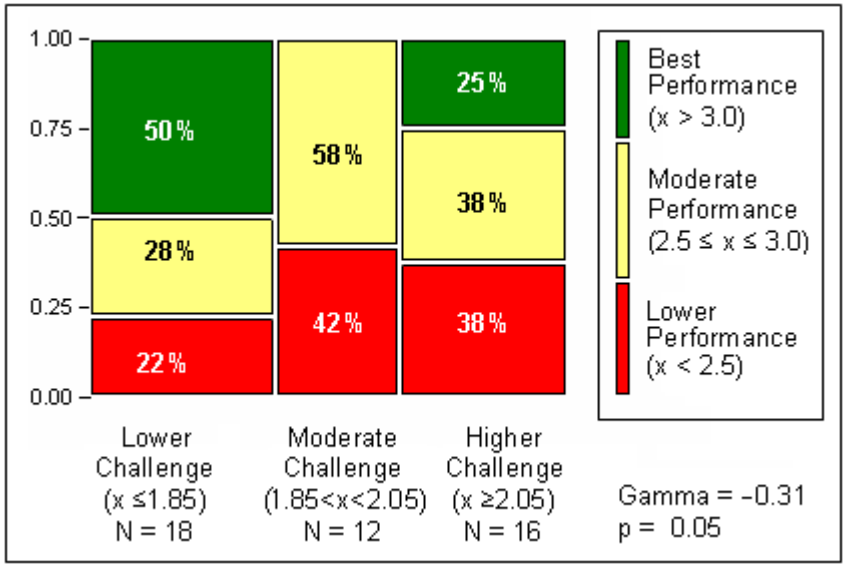

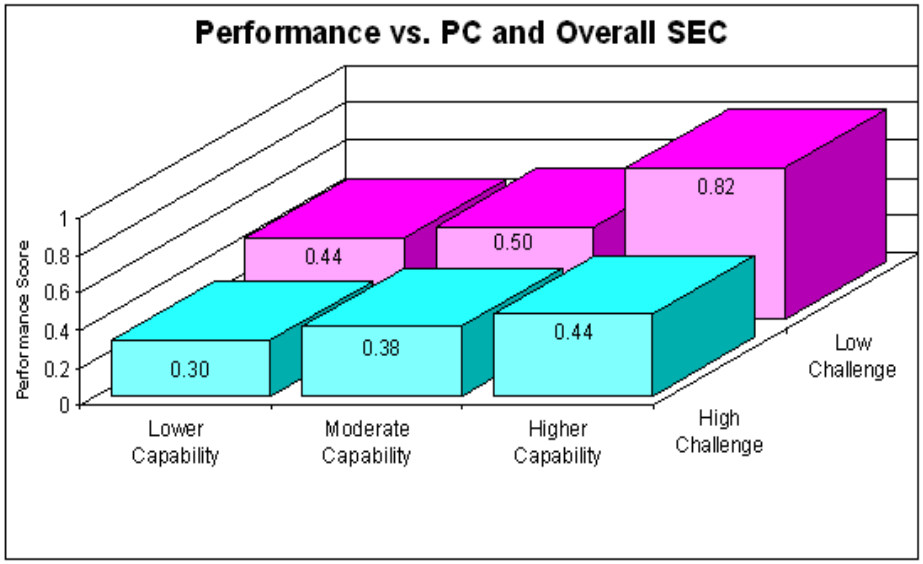

Summary of Relationships

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
Project Monitoring and Control	Weak negative	-0.13
Process Improvement	Weak positive	+0.05