



The quest for evidence of the Value of Systems Engineering:

“a long, uphill road”

Is Systems Engineering effective ?

Does it provide a return on the investment?

The answer can differ depending on one's *perspective*

Systems Engineers

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.

Program Managers

We should **reduce 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.

Without **FACTS**, these are just **ASSERTIONS!**

Systems Engineers

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Proceedings of the International Symposium, INCOSE, 2000:

“Many INCOSE members are dismayed that there are no hard numbers to justify implementation of systems engineering process improvement.”

The Shangri-La of ROI, Sarah A. Sheard and Christopher L. Miller

- 1. There are no “hard numbers”**
- 2. There will be no hard numbers in the foreseeable future**
- 3. If there were hard numbers, there wouldn't be a way to apply them to your situation**
- 4. if you did use such numbers, no one would believe you anyway**

The Shangri-La of ROI, Proceedings of the International Symposium, INCOSE, 2000, Sarah A. Sheard and Christopher L. Miller

Main issues:

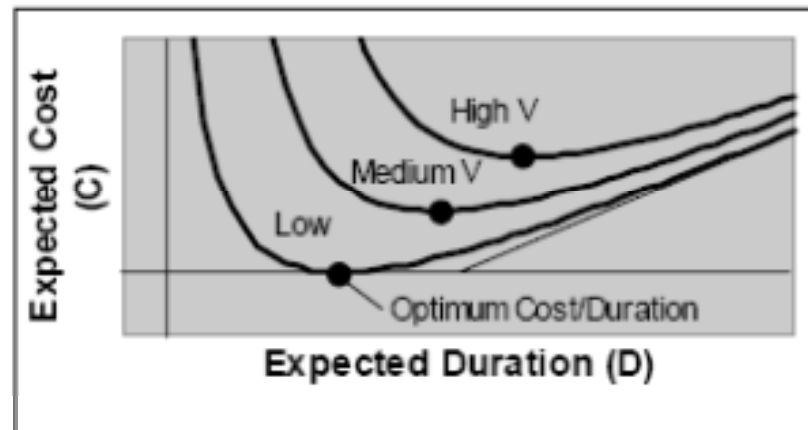
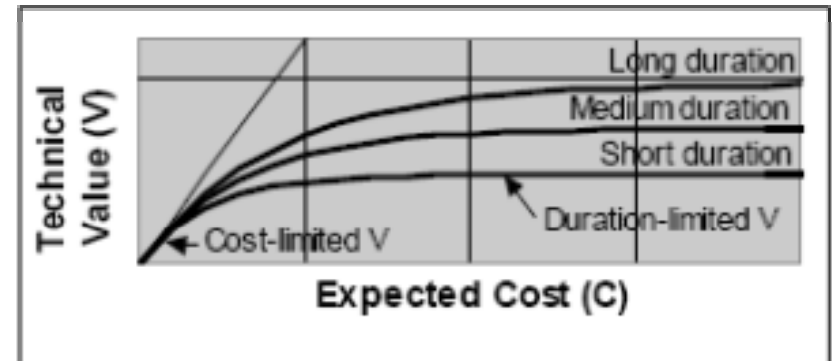
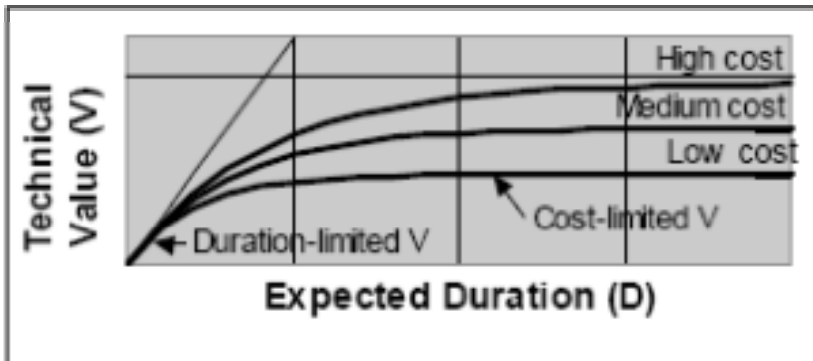
- **Common definition of return values**
- **Bias**
- **Definition of Systems Engineering**
- **Comparison to surveyed companies**
- **Separability of causes**
- **Estimation model nonlinearity**
- **How process improvement is done**

The Shangri-La of ROI, Proceedings of the International Symposium, INCOSE, 2000, Sarah A. Sheard and Christopher L. Miller

**Despite these caveats, the INCOSE
Systems Engineering Center of Excellence
decided to take up the challenge with the project:**

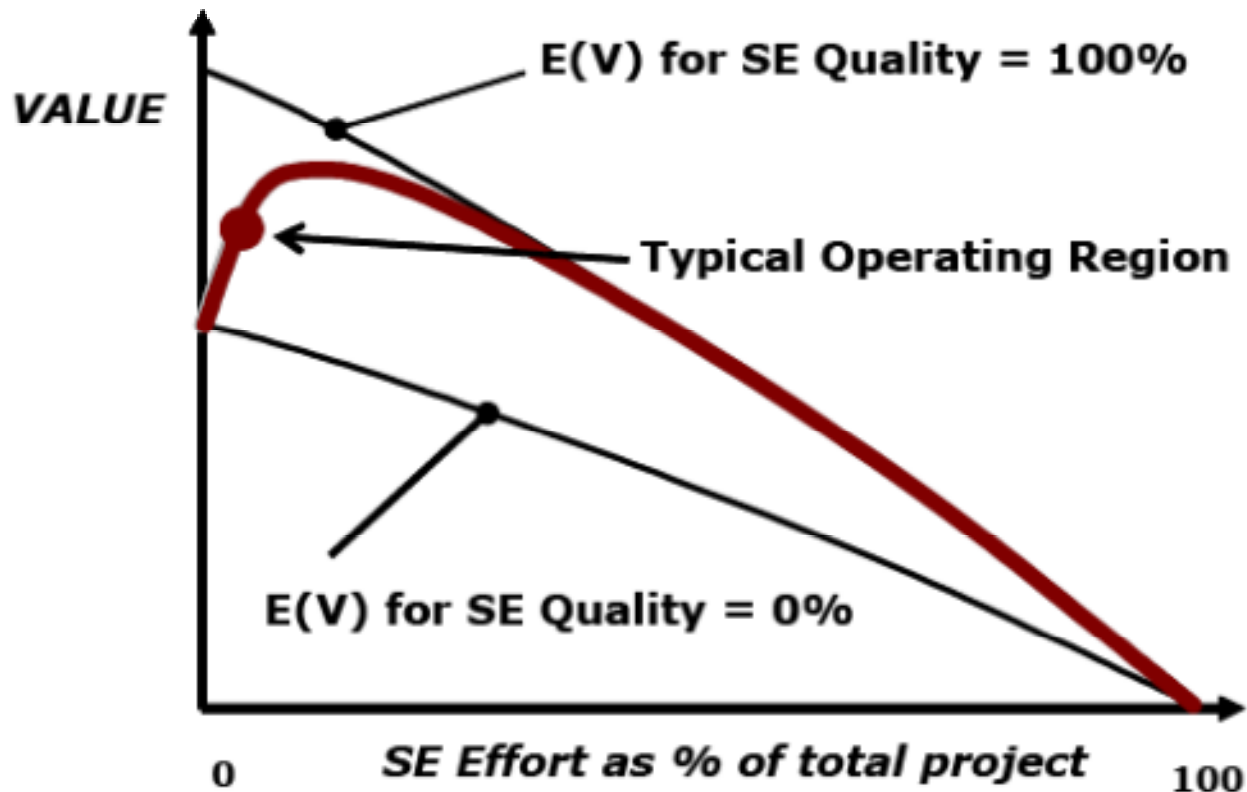
Value of Systems Engineering

Heuristic Relationships



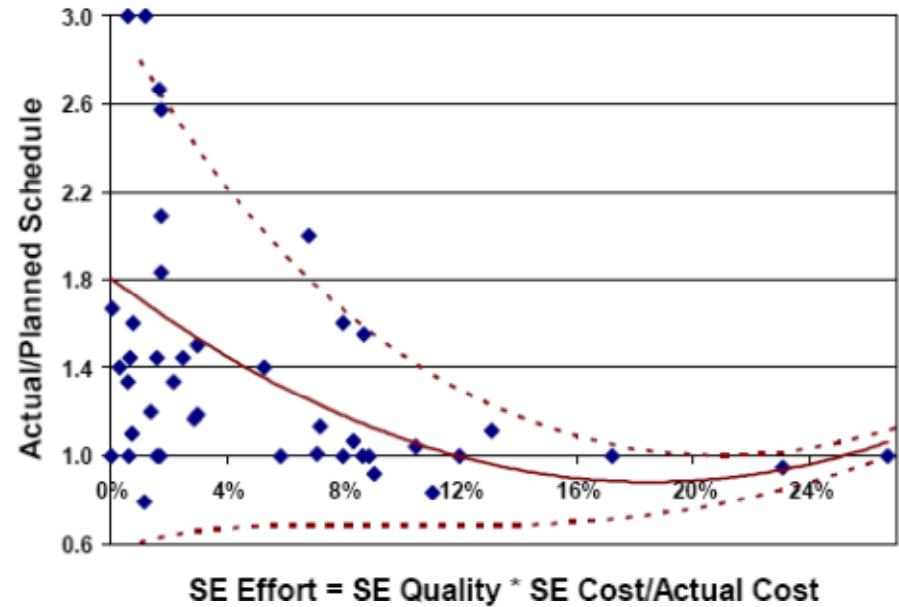
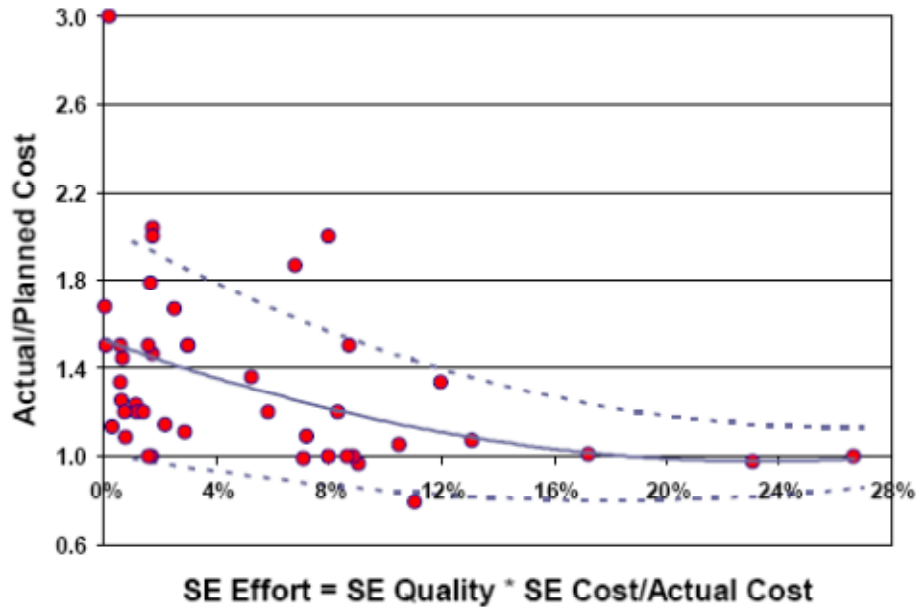
Toward a Mathematical Theory of Systems, Engineering Management, Eric C. Honour, Honourcode, Inc.

Heuristic Relationships



Understanding the Value of Systems Engineering, Eric C. Honour, INCOSE International Symposium Proceedings, 2004

44 Projects survey results



Understanding the Value of Systems Engineering, Eric C. Honour, INCOSE International Symposium Proceedings, 2004

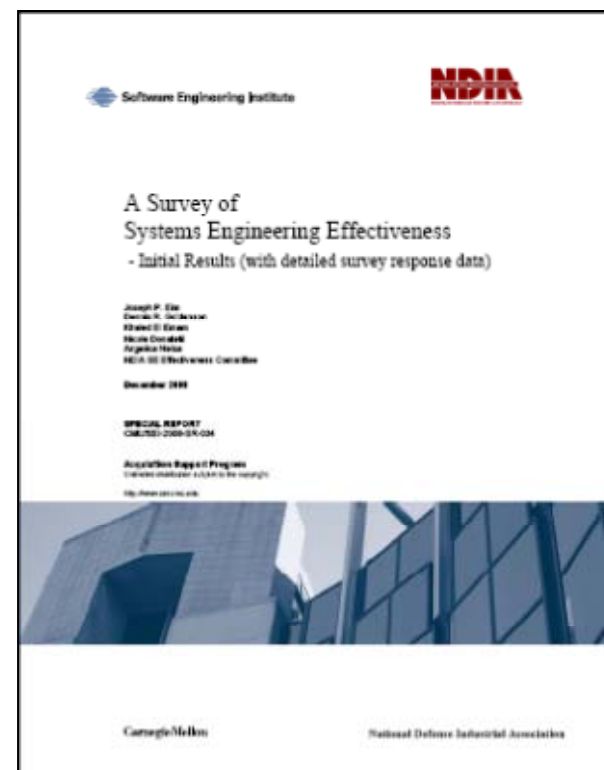
In 2005, The Office of the Under Secretary of Defense (AT&L) tasked the NDIA Systems Engineering Division to research and report on the costs and benefits associated with Systems Engineering practices in the acquisition and / or development of military systems.

The **Systems Engineering Division (SED)** of the **National Defense Industrial Association (NDIA)** established the **Systems Engineering Effectiveness Committee (SEEC)** to obtain quantitative evidence of the effect of Systems Engineering (SE) best practices on Project Performance.

The SEEC developed and executed a:

“**Survey of Systems Engineering Effectiveness**”

The survey was developed as a collaborative effort between the **NDIA SEEC** and the **Software Engineering Institute of Carnegie Mellon University**.



GOAL:

“Identify the degree of statistical association between the use of specific Systems Engineering practices and activities on projects, and quantitative measures of Project Performance”

The HYPOTHESIS:

“The effective performance of SE best practices on a development program yields quantifiable improvements in the program execution (for example, improved cost performance, schedule performance, technical performance)”

SURVEYED POPULATION

Focus on: “**major government contractors and subcontractors**” “**that supply products**(as opposed to services)”

After filtering for these criteria, a list of **50 companies** to invite to participate to the survey was produced out of the 485 active SED members.

Eventually a total of **64 programs** was surveyed.

SURVEY METHODOLOGY

The definition of the methods to be used to assess the application of SE practices to projects, was hampered by the fact that **a widely accepted definition of what constitutes SE does not exist.**

To overcome this obstacle, the SEEC chose to **survey specific activities** that would normally be **regarded as elements of SE.**

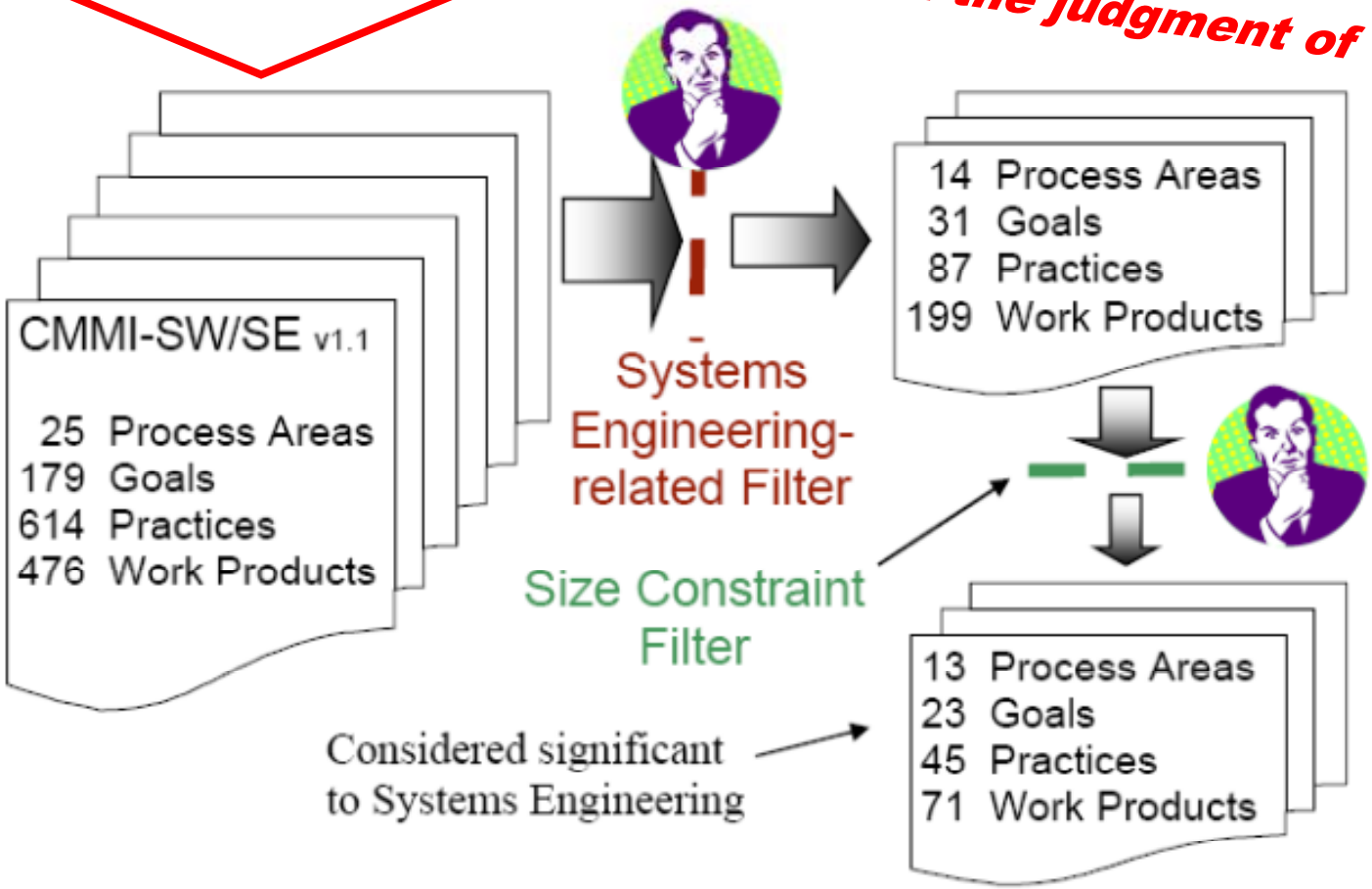
The SEEC chose to base this assessment primarily upon the **Capability Maturity Model Integration (CMMI-SE/SW/IPPD Model v1.1)**

Survey content is based on a recognized standard (CMMI)

Extract all listed work products from the CMMI

Identify work products that result from Systems Engineering activities

“in the judgment of the SEEC”



Extract those work products that are most significant

The primary survey hypothesis in mathematical form:

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

where:

***Perf* = Project Performance**

***PC* = Project Challenge**

***PE* = Project Environment**

***AC* = Acquirer Capability**

***SEC* = Systems Engineering Capability**

The **Project Performance (Perf) *composite variable*** combines three components:

- **Cost Performance (PerfC)**
- **Schedule [Duration] Performance (PerfD)**
- **Scope Performance (PerfS)**

The **Project Challenge (PC)** measure combines a number of diverse factors contributing to the difficulty of a project (e.g., project **size**, project **complexity**, technology **precedents**, and others) into a ***single measure***.

The three **Project Environment (PE)** measures:

- the development organization's **CMMI-related capabilities (PECMMI)**
- the development organization's **process improvement efforts (PEIMP)**
- the development organization's **prior experience (PEEXP)**.

were ***evaluated individually*** for their impact on Project Performance

The **Acquirer Capability (AC)** combines a few parameters into a *single measure*:

- **acquirer's participation** on Integrated Project Teams (**IPTs**)
- **acquirer's provision** of a Systems Engineering Plan (**SEP**)
- **system requirements**:
 - **quality**
 - **completeness**
 - **stability**

Systems Engineering Capability (SEC) was decomposed into 12 measures of SE Capability in specific process areas:

- IPT-Based Capability (SECIPT)
- Project Planning (SECPP)
- Project Monitoring and Control (SECPMC)
- Risk Management (SECRSKM)
- Requirements Development and Management (SECREQ)
- Technical Solution (= SECTRADE + SECARCH) (SECTS)
 - Trade Studies (SECTRADE)
 - Product Architecture (SECARCH)
- Product Integration (SECPI)
- Verification (SECVER)
- Validation (SECVAL)
- Configuration Management (SECCM)

Analysis of CMMI to Identify and Select SE-related Work Products

Goal	PRACTICE	WORK PRODUCT (WP)	SE WP	Key SE WP	Survey Question
Technical Solution					
SG 1: Select Product-Component Solutions - Product or product-component solutions are selected from alternative solutions.	SP 1.1-1: Develop Alternative Solutions and Selection Criteria - Develop alternative solutions and selection criteria.	Alternative solutions	Y	Y	RD12
		Selection criteria	Y	Y	RD12
	SP 1.1-2: Develop Detailed Alternative Solutions and Selection Criteria - Develop detailed alternative solutions and selection criteria.	Alternative solution screening criteria	Y	Y	
		Evaluations of new technologies	Y		
		Alternative solutions	Y	Y	
		Selection criteria for final selection	Y	Y	
	SP 1.2-2: Evolve Operational Concepts and Scenarios - Evolve the operational concept, scenarios, and environments to describe the conditions, operating modes, and operating states specific to each product component.	Product-component operational concepts, scenarios, and environments for all product-related life-cycle processes (e.g., operations, support, training, manufacturing, deployment, fielding, delivery, and disposal)	Y		
		Timeline analyses of product-component interactions	Y		
		Use cases	Y		
	SP 1.3-1: Select Product-Component Solutions - Select the product-component solutions that best satisfy the criteria established.	Product-component selection decisions and rationale	Y	Y	
		Documented relationships between requirements and product components	Y		
		Documented solutions, evaluations, and rationale	Y		

Survey Questionnaire

RD11

11. Stakeholders impacted by trade studies are involved in the development and performance of those trade studies

Strongly Disagree Disagree Agree Strongly Agree

RD12

12. This project performs and documents trade studies between alternate solutions based upon definitive and documented selection criteria

Strongly Disagree Disagree Agree Strongly Agree

RD13

13. Documentation of trade studies is maintained in a defined repository and is accessible to all relevant project staff

Strongly Disagree Disagree Agree Strongly Agree

Response Distributions for Individual Survey Questions

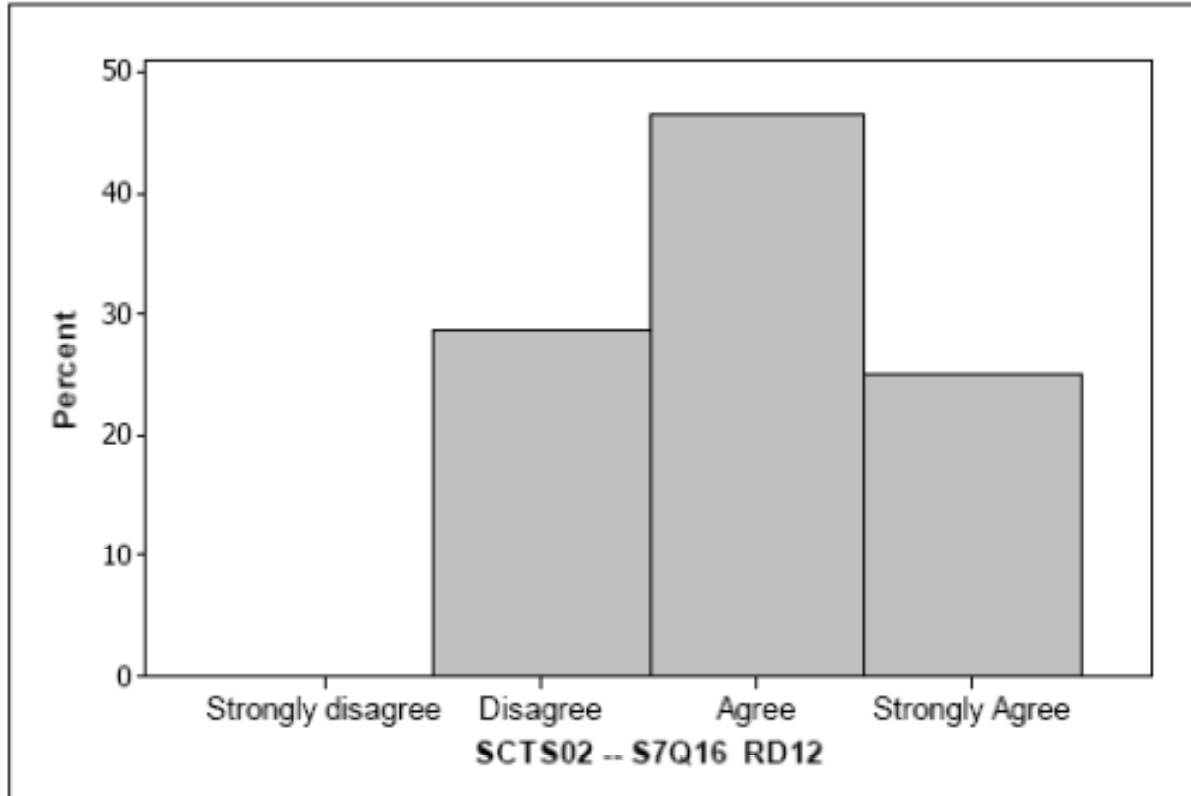


Figure 183: RD12 - This Project Performs and Documents Trade Studies Between Alternate Solutions Based Upon Definitive and Documented Selection Criteria

Application of Trade Study best practices [Trade Studies Capability (SEC_{TRADE})] was identified through questions RD11 through RD13

ID	Question	Response range
<i>RD11</i>	Stakeholders impacted by trade studies are involved in the development and performance of those trade studies	<ul style="list-style-type: none"> • strongly disagree • disagree • agree • strongly agree
<i>RD12</i>	This project performs and documents trade studies between alternate solutions based upon definitive and documented selection criteria	<ul style="list-style-type: none"> • strongly disagree • disagree • agree • strongly agree
<i>RD13</i>	Documentation of trade studies is maintained in a defined repository and is accessible to all relevant project staff	<ul style="list-style-type: none"> • strongly disagree • disagree • agree • strongly agree

The horizontal range is divided into a number of equally sized bins.

The vertical bars represent the percentage of respondents whose score falls within the range of each bin

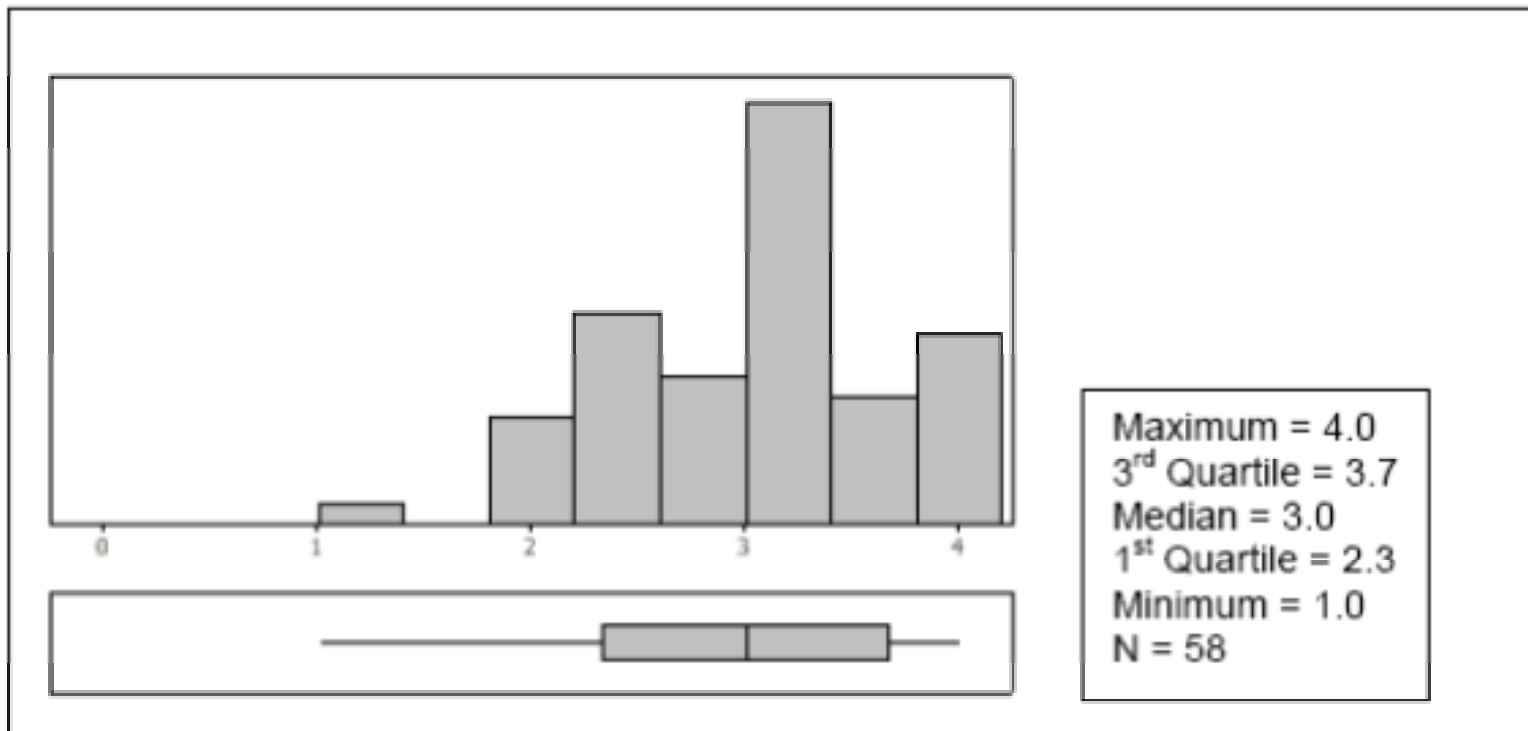
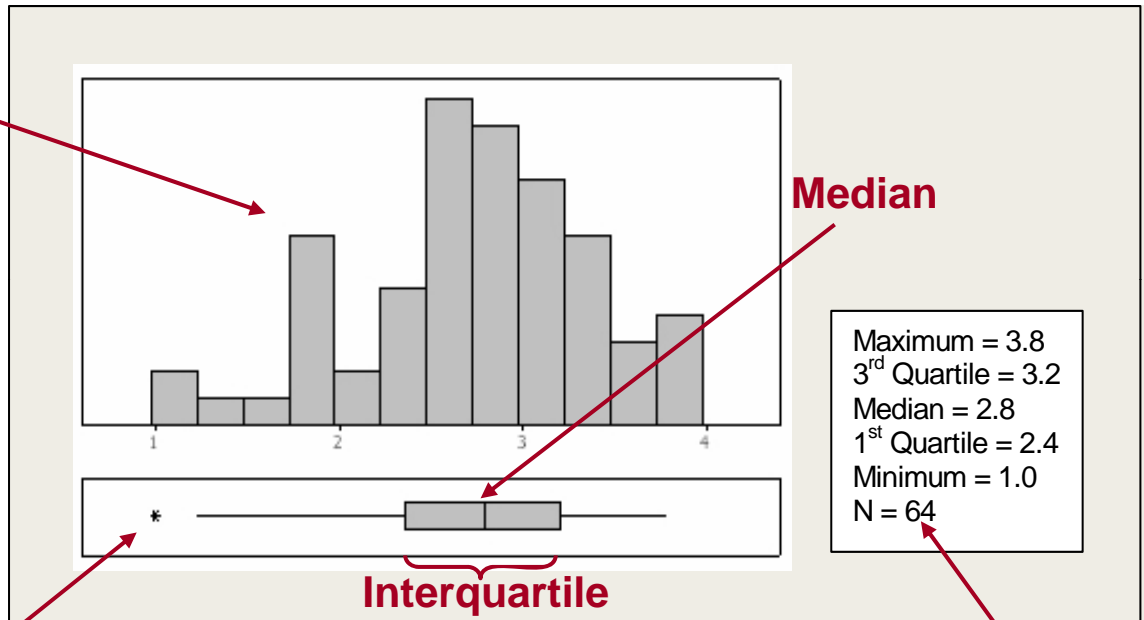


Figure 24: Trade Study Capability (SEC_{TRADE}) Composite Measure

Histogram of response frequencies



Median

Maximum = 3.8
3rd Quartile = 3.2
Median = 2.8
1st Quartile = 2.4
Minimum = 1.0
N = 64

Outliers

Interquartile Range

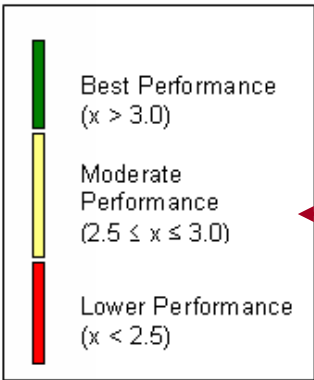
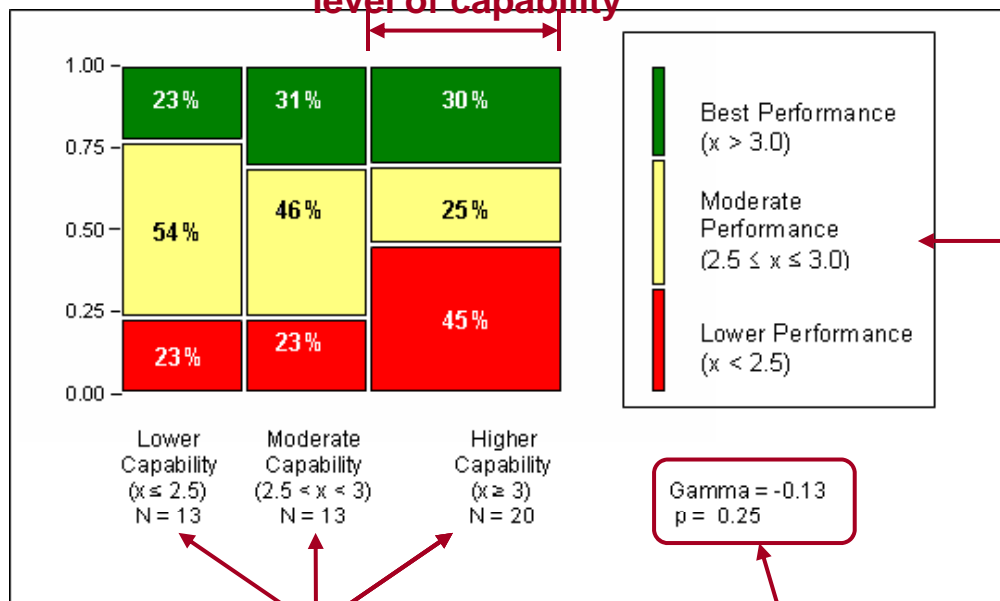
Data Range

**Sample size
(responses to corresponding survey questions)**

Outlier: any value that lies more than one and a half times the length of the box from either end of the box

Mosaic chart key

Column width represents proportion of projects with this level of capability



Relative performance distribution of the sample

Gamma = -0.13
p = 0.25

Gamma: measures strength of relationship between two ordinal variables

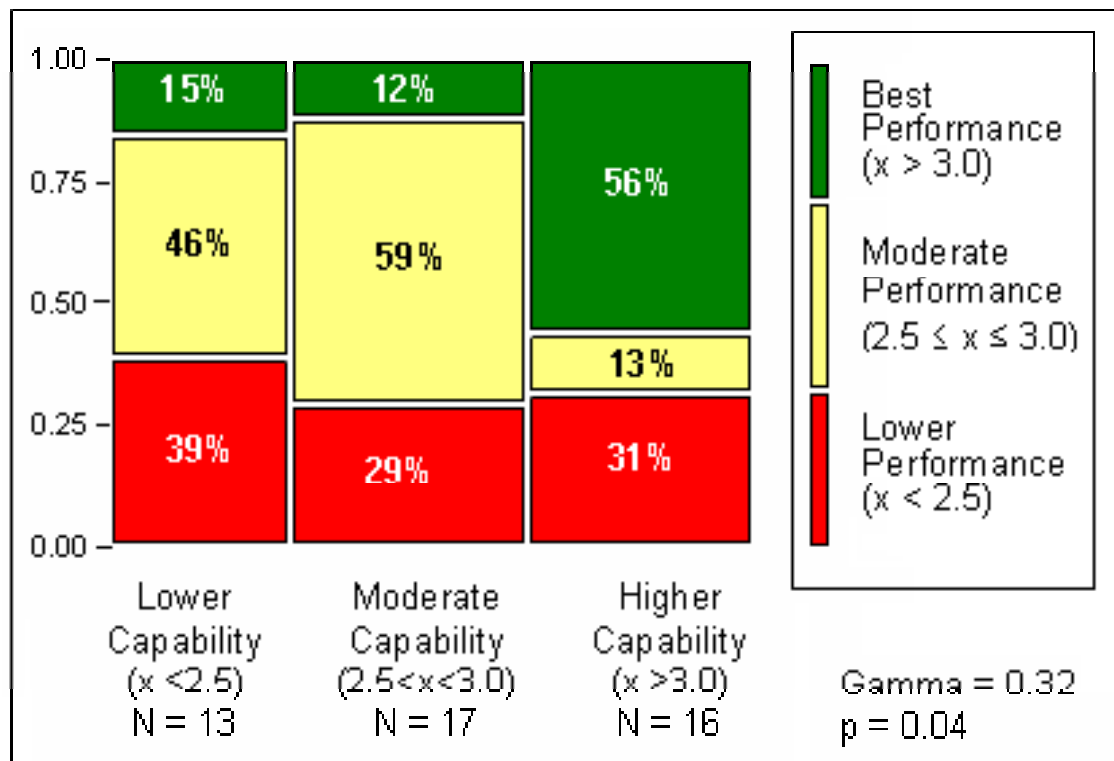
p: probability that an associative relationship would be observed by chance alone

Gamma	Relationship
< 0.2	Weak
~ 0.3	Moderately strong
~ 0.5	Strong
> 0.6	Very strong

Projects exhibiting a given level of relative capability (Lowest, Intermediate, Highest)
Sample size and distribution for associated survey responses (capability + performance)

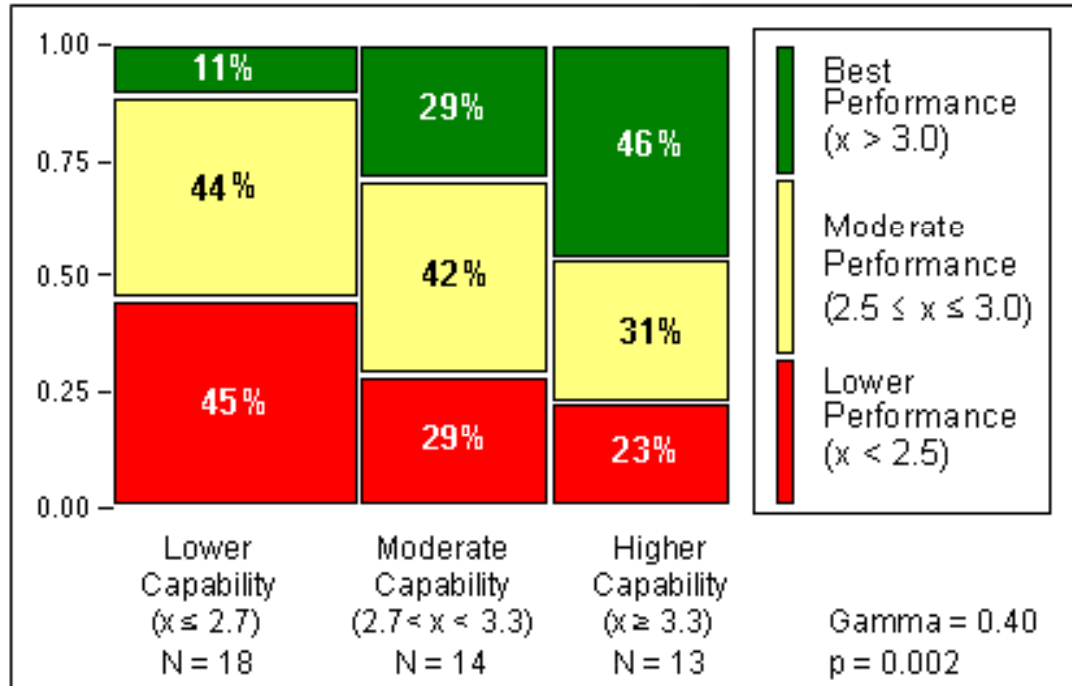
Measures of association and statistical test

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



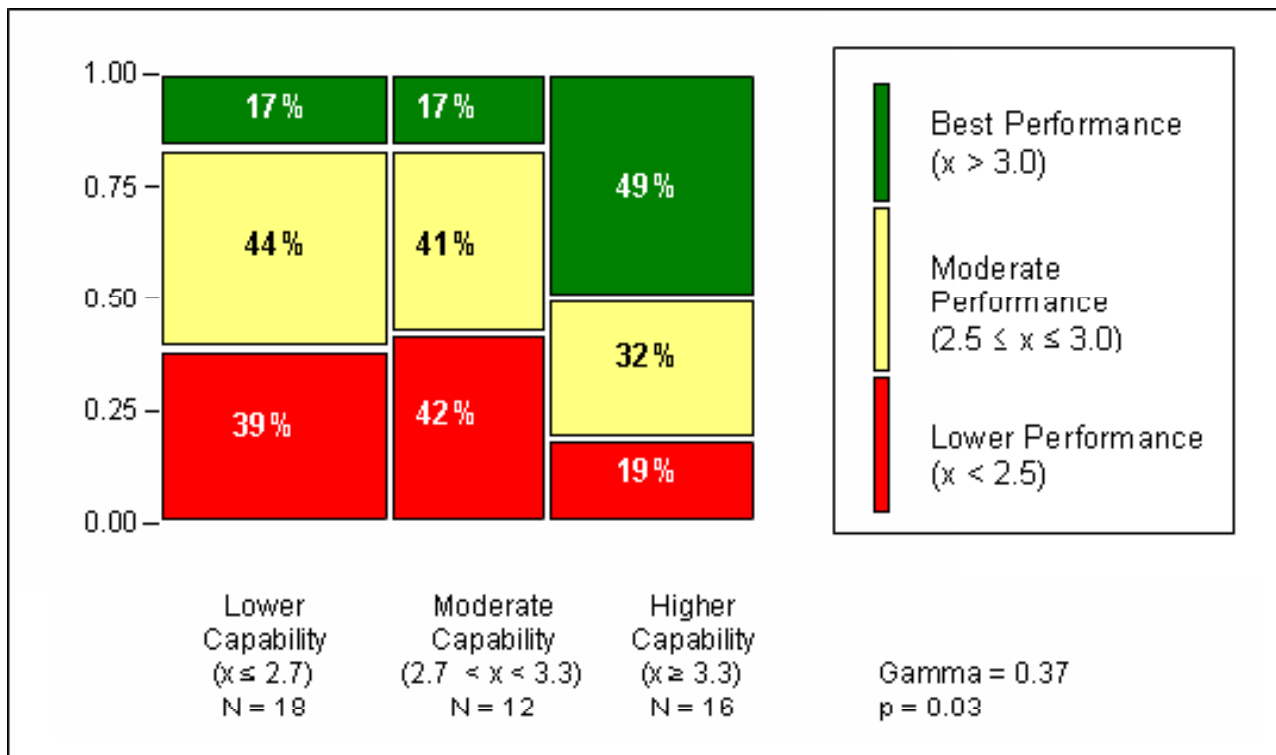
Projects with better Systems Engineering Capabilities deliver better Project Performance (cost, schedule, functionality)

Product Architecture and Performance



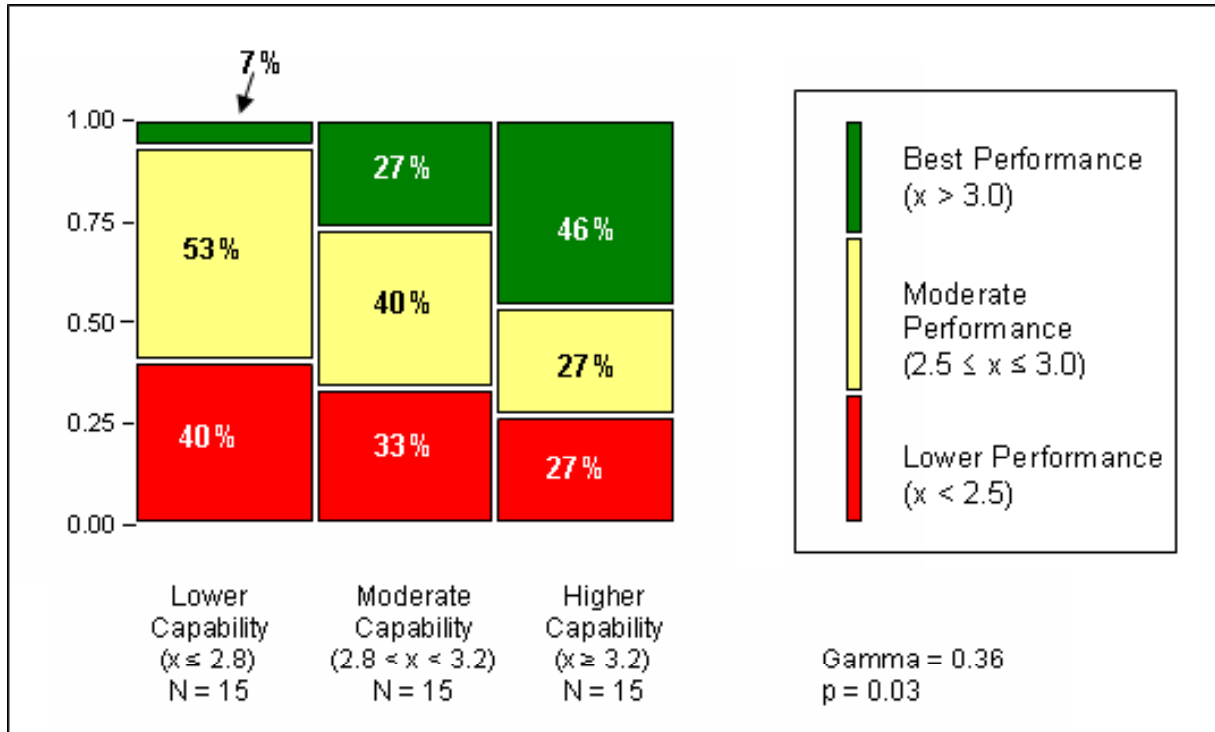
Projects with better Product Architecture show a “Moderately Strong / Strong” Positive Relationship with Performance

Trade Studies and Project Performance



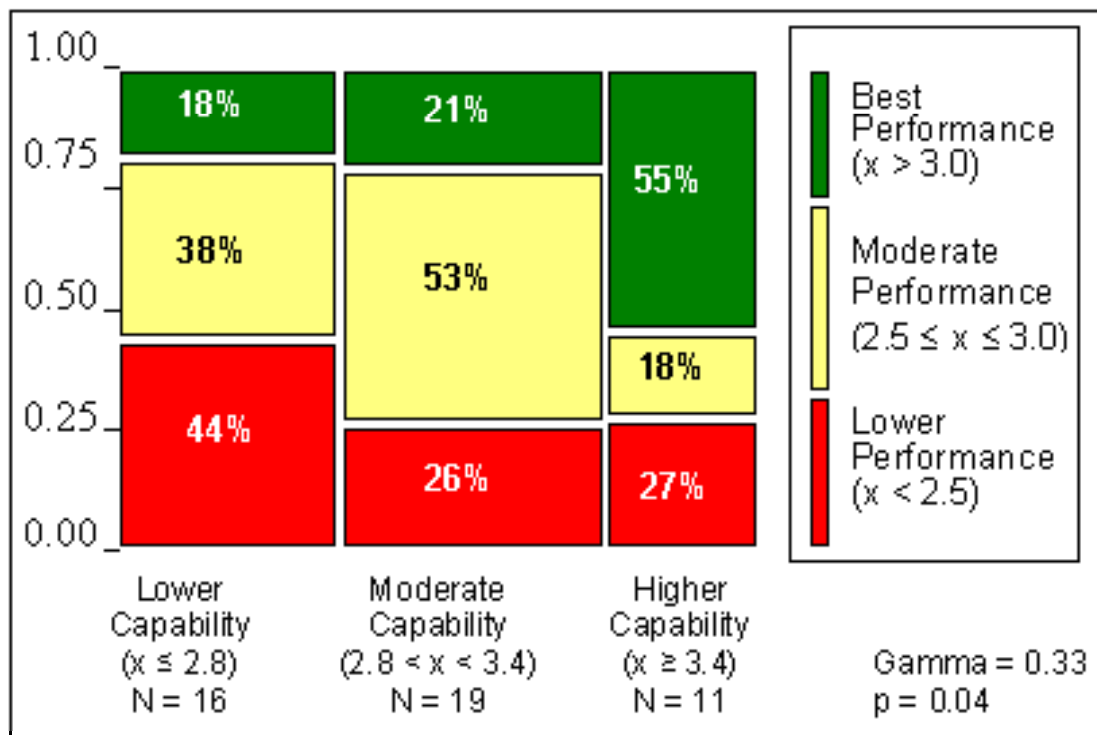
Projects with better Trade Studies show a “Moderately Strong / Strong” Positive Relationship with Performance

Technical Solution and Project Performance



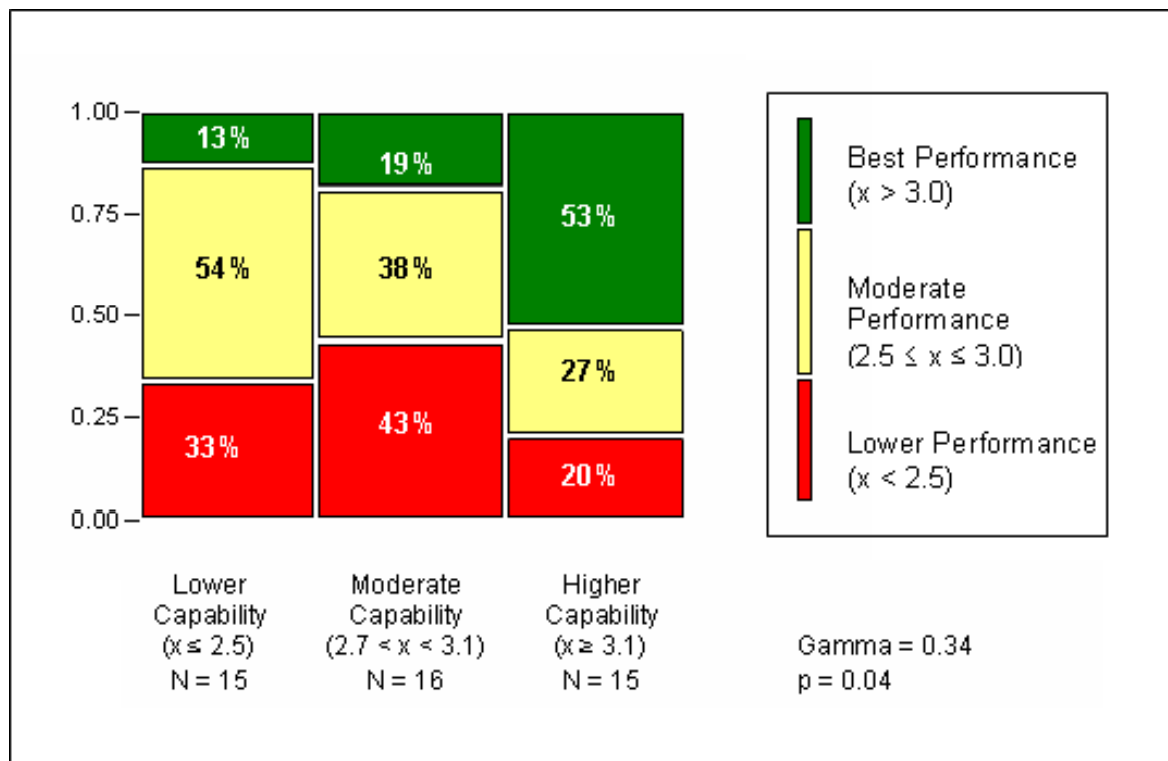
Projects with better Technical Solution show a “Moderately Strong” Positive Relationship with Performance

Requirements and Performance



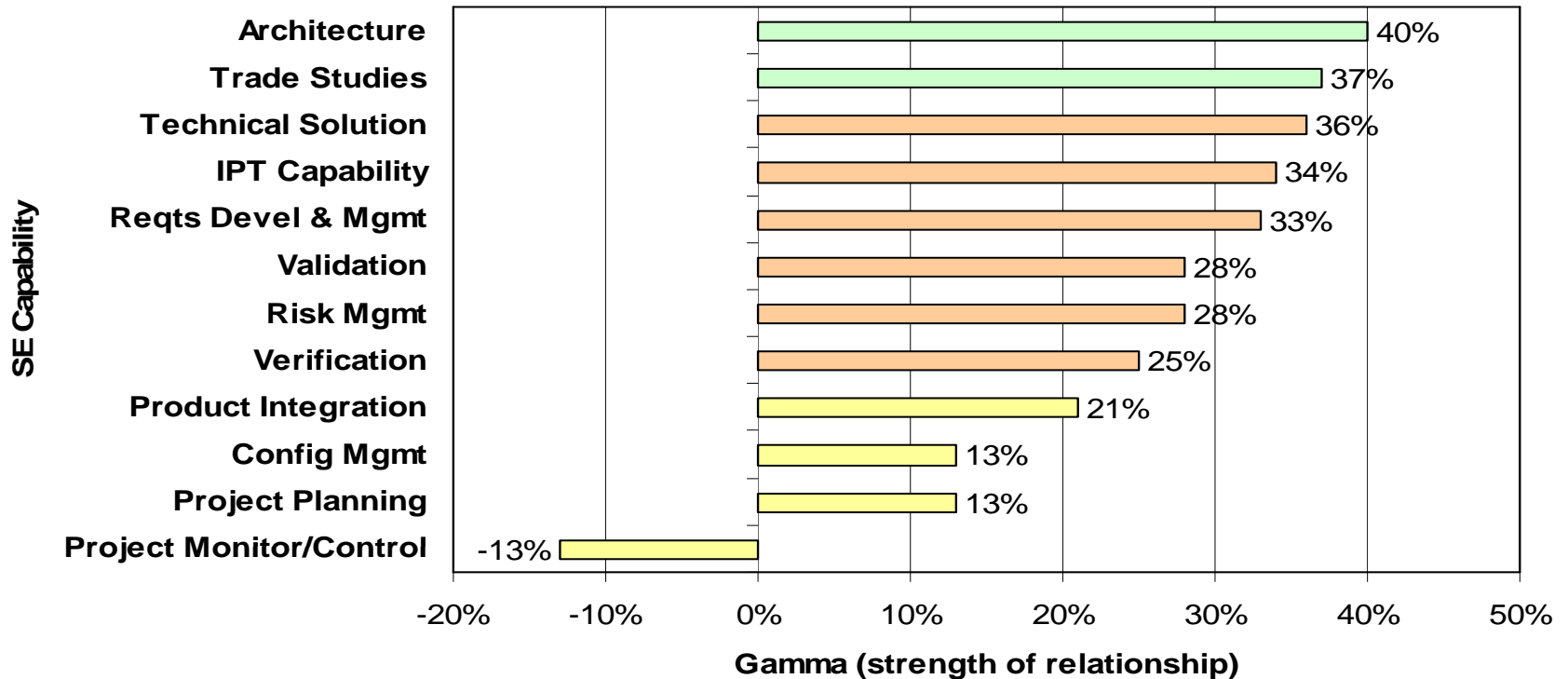
Projects with better Requirements Development and Management show a “Moderately Strong” Positive Relationship with Performance

IPT-Related Capability and Performance



Projects with better IPTs show a “Moderately Strong” Positive Relationship with Performance

Relationship of SE Processes to Program Performance



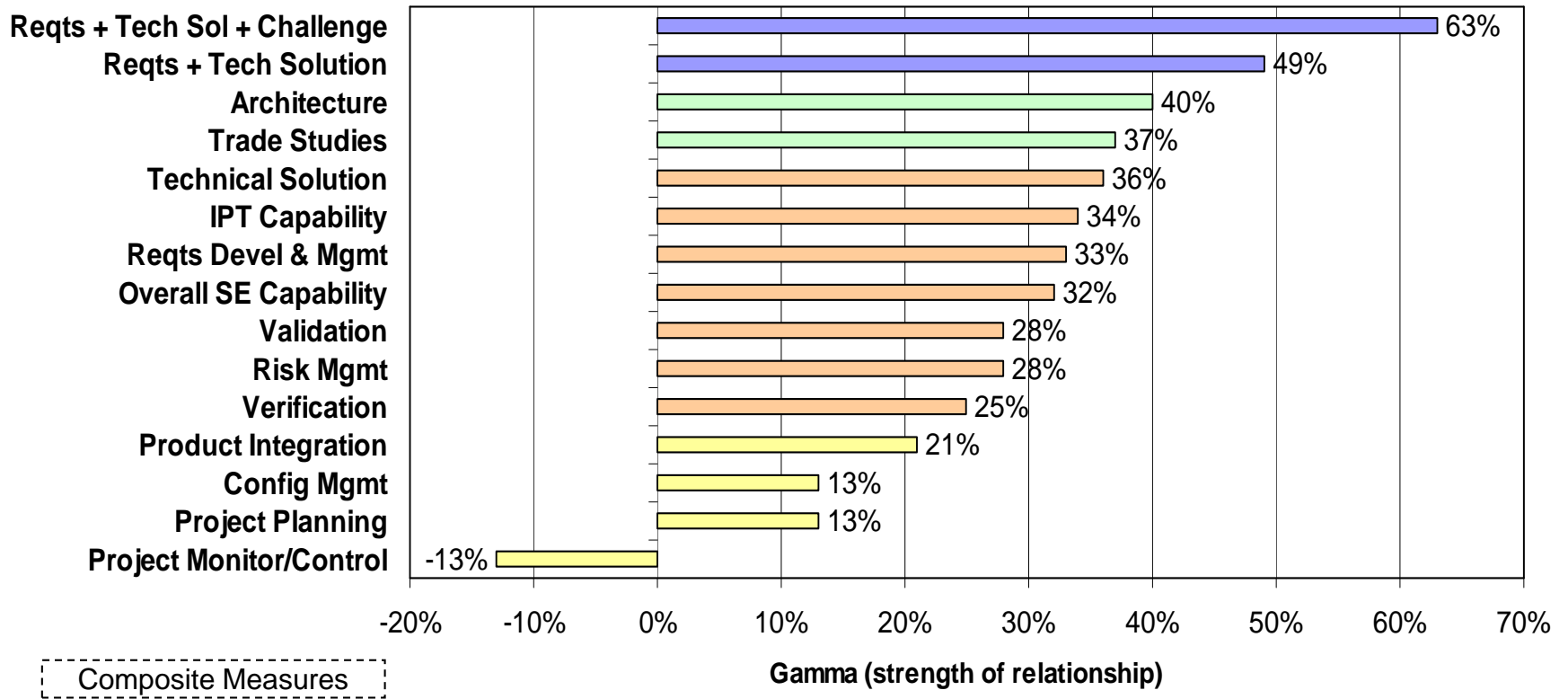
Strong Relationship

Moderately Strong to Strong Relationship

Moderately Strong Relationship

Weak Relationship

Relationship of SE Processes to Program Performance



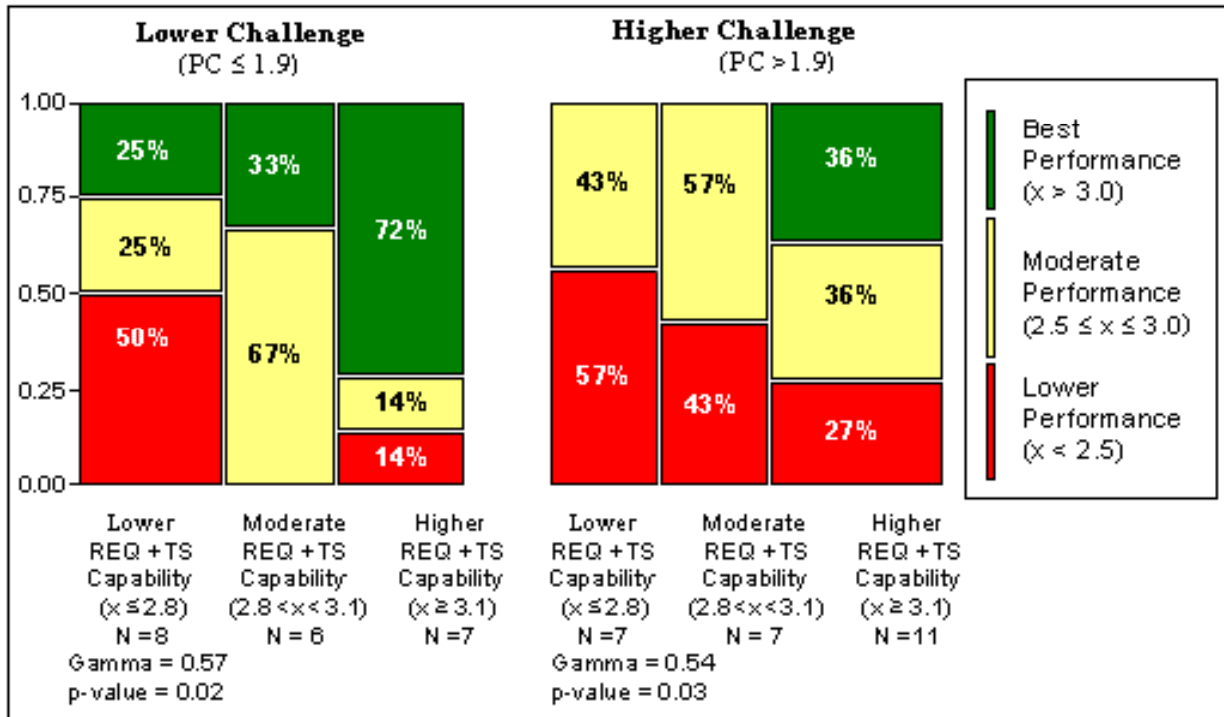
Strong Relationship

Moderately Strong to Strong Relationship

Moderately Strong Relationship

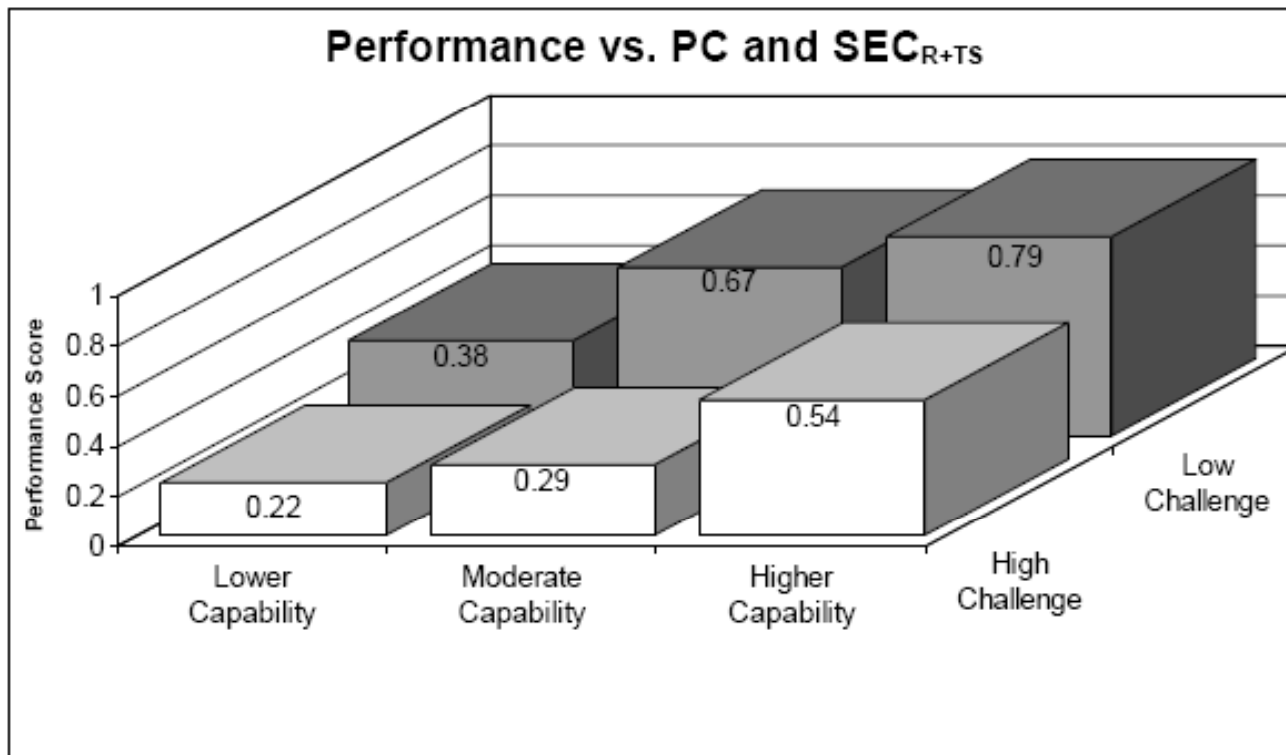
Weak Relationship

Reqs + Tech Solution controlled by Project Challenge



Projects with higher Requirements and Technical Solution capability are better able to achieve higher performance even in challenging programs

Performance vs. Project Challenge and Requirements + Technical Solution SE Capability



Conclusions & Caveats - *Summary*



1. **SE Effectiveness Survey**: Provided credible measured evidence about the value of disciplined SE to Improved Program Performance.
 - Affects success of systems- development projects
2. **Specific Systems Engineering Best Practices**: Highest relationships to activities on the “left side of SE Vee”
 - Architecture
 - Trade Studies
 - Reqs Devel & Mgmt
3. **The environment (Project Challenge) affects performance too**: Some projects are more challenging than others ...yet good SE practices remain crucial for both high and low challenge projects

CREDITS

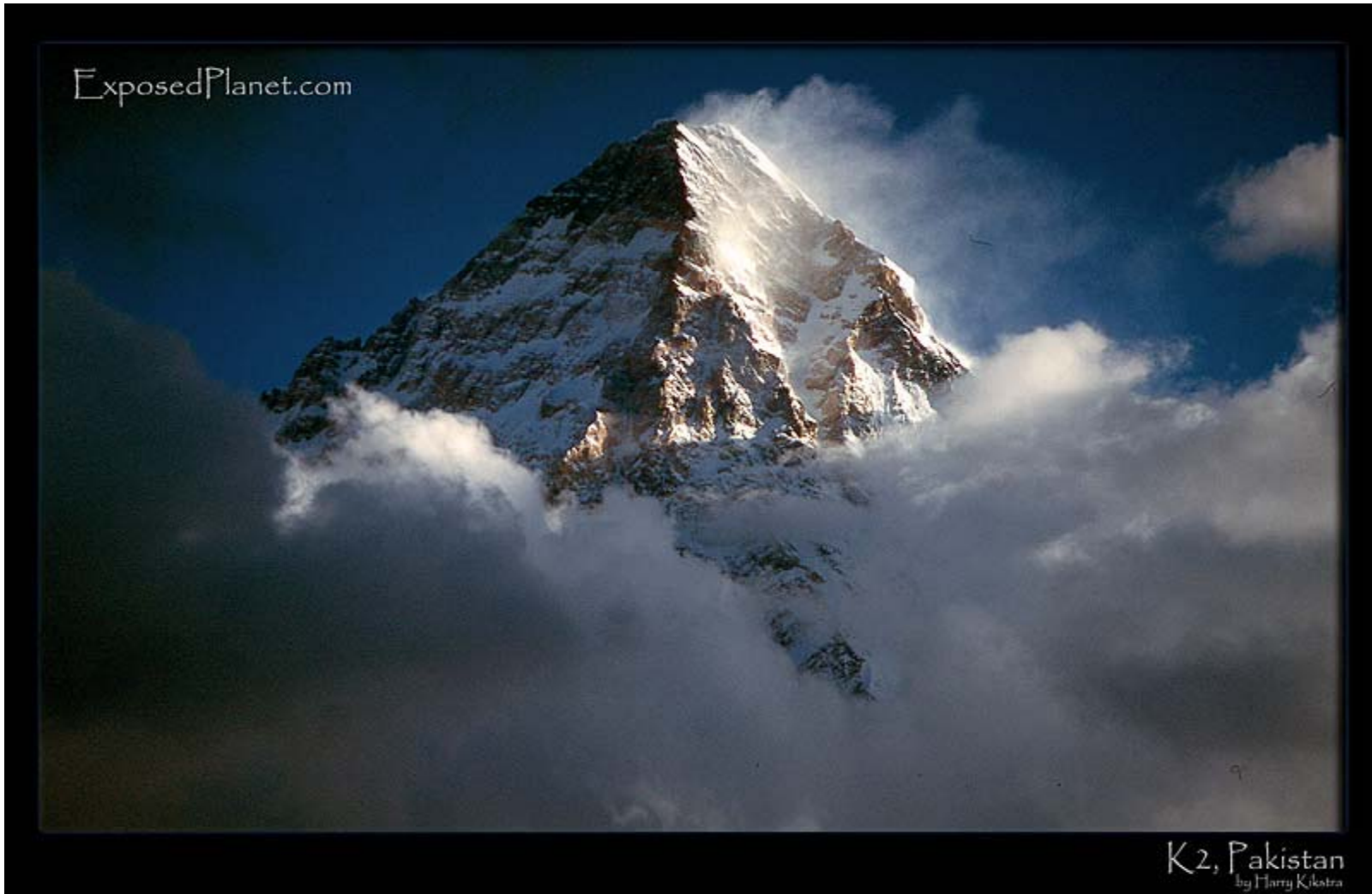
Material for this presentation is derived by the following documents:

- SPECIAL REPORT CMU/SEI-2008-SR-034, "**A Survey of Systems Engineering Effectiveness - Initial Results**", Joseph P. Elm, Dennis R. Goldenson, Khaled El Emam, Nicole Donatelli, Angelica Neisa, NDIA SE Effectiveness Committee, Carnegie Mellon University, Software Engineering Institute, Acquisition Support Program, December 2008
<http://www.sei.cmu.edu/publications/documents/08.reports/08sr034.html>
- A Survey of Systems Engineering Effectiveness by: NDIA Systems Engineering Effectiveness Committee, INCOSE - Orlando Chapter, Geoff Draper, February 28, 2008 - presentation

The Results!

**Projects with better
Systems Engineering
capabilities deliver
better Project
Performance!**

But we have not yet reached the summit!



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