INCOSE Canada Chapter is grateful to

DR. ERIC HONOUR

for providing his slides which accompanied his presentation on

SYSTEMS ENGINEERING RETURN ON INVESTMENT

at the INCOSE Canada Chapter's mini-conference

Systems Engineering Principles Transcend all Domains Focusing on the Value of System Engineering in Delivering Large Complex Systems

Saturday Sept.28, 2013
Ottawa, Ontario.

This file available at: http://incosecanada.weebly.com

Honourcode, Inc.

Systems Engineering Return on Investment

What is "systems engineering" and how much is enough?

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Funding provided by
- *Honourcode, Inc.*
- *DASI (Univ of South Australia)*

University of South Australia
Defence and Systems Institute

Agenda

- **Systems Engineering**
  - **What is it? Why is it?**
- **SE-ROI Project**
  - **Motivation: How much is enough?**
  - **Goals and methodology**
- **SE-ROI Results**
  - **Primary correlations: success* vs. SE**
  - **Eight SE Activities: front-end vs. back-end**
  - **Right-Sizing SE**

**Cost compliance, schedule compliance, stakeholder overall success, technical quality*

Bottom Line

- Systems Engineering is the engineering of complexity
  - More than a process – a way of thinking
- SE target: 14% of a development project
- Better programs use more mission definition, more technical leadership
  - Better cost/schedule control, stakeholder success
- Today's process-based SE does not correlate with system technical quality

SE today leads to better programs – but does not lead to better systems.

- Results can be used to right-size SE

Systems Engineering

What is this strange discipline?

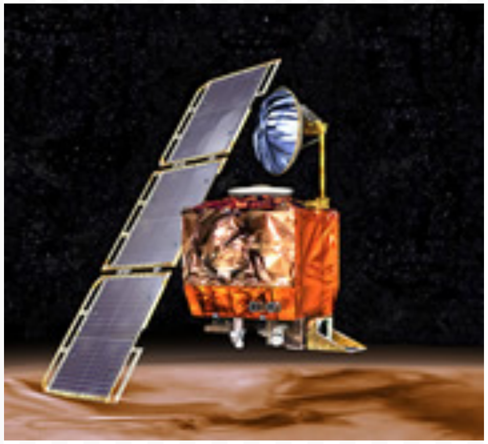
Systems Engineering

- ***Interdisciplinary approach and means to enable the realization of successful systems***
  - Defining customer needs and required functionality early in the development cycle
  - Documenting requirements
  - Proceeding with design synthesis and system validation
- ***Considers the complete problem***: Operations, Cost & Schedule, Performance, Training, Support, Test, Disposal, Manufacturing
- ***Integrates all disciplines*** and specialty groups into a team effort, structured development from concept to production to operation
- ***Considers both business and technical needs*** of all customers with the goal of providing a quality product that meets the user needs.

INCOSE Definition

Mars Climate Orbiter

- Launched Dec 98 at Kennedy
- Arrived at Mars in Sep 99
  - 16 minute orbit insertion burn
  - Passed behind Mars during burn
  - No further contact



- Failure causes
  - Asymmetric solar panels and solar wind
  - No "BBQ" mode to flip asymmetry
  - "Small factor" ground-based correction software operating in English units versus Metric
  - Intended approach 140km altitude; actual approach 57km
- Development $193M; launch $92M

Systems Engineering Objective

…is to effectively engineer systems

- **Meet the operational and customer needs**
  - **Functional and Performance**
  - **Schedule**
  - **Total Ownership Cost**
- **Fit within the intended system environment**
- **Provide sufficient robustness and reliability**
- **Offer appropriate flexibility**
- **Consider the entire life cycle**

Systems Engineering Scope

Technical aspects
- System definition
- System analysis
- System architecting
- System realization
- Verification

Management aspects
- Technical planning
- Technical assessment
- Technical control

Leadership aspects
- Technical team creation
- Team nurturing
- Team cohesion

Moti Frank (2000) The Cognitive Characteristics of Successful Systems Engineers, INCOSE

Properties of Complex Systems

Property	Simple Systems	Complex Systems
Predictability	No surprises	Surprise behavior
Connectedness	Few components, Simple interfaces, Little feedback	Many components, Complicated interfaces, Much feedback
Control	Centralized or few, Traceable, Fixed behavior	Diffusion of control, Nontraceable, Adaptable
Decomposability	Weak interactions, Severable components, Decomposable	Many interactions, All elements essential, Irreducible

Toaster **Internet**

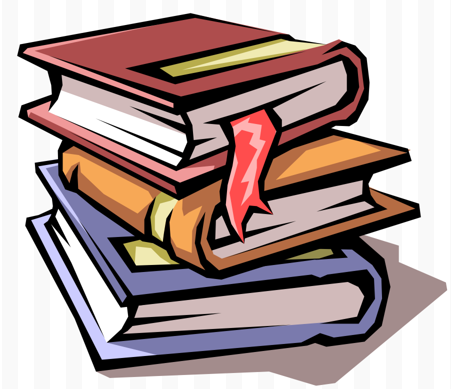
Increasing Complexity of Systems…

- Not sufficient to do Systems Engineering by rote
- Premium is on the ability to ...
  - Rapidly decide, as situations develop, what is to be done, how, who with, & how to measure success
  - Rapidly assemble tailored diverse multi-disciplinary teams and get them operational and effective,
  - Maintain effectiveness under unpredictable and rapidly evolving conditions, retaining ability to raise additional tasks as needed
- Dynamic properties of the capability 'emerge' as a result of many decisions about structure, process, strategies, values, personnel, technology, training, …

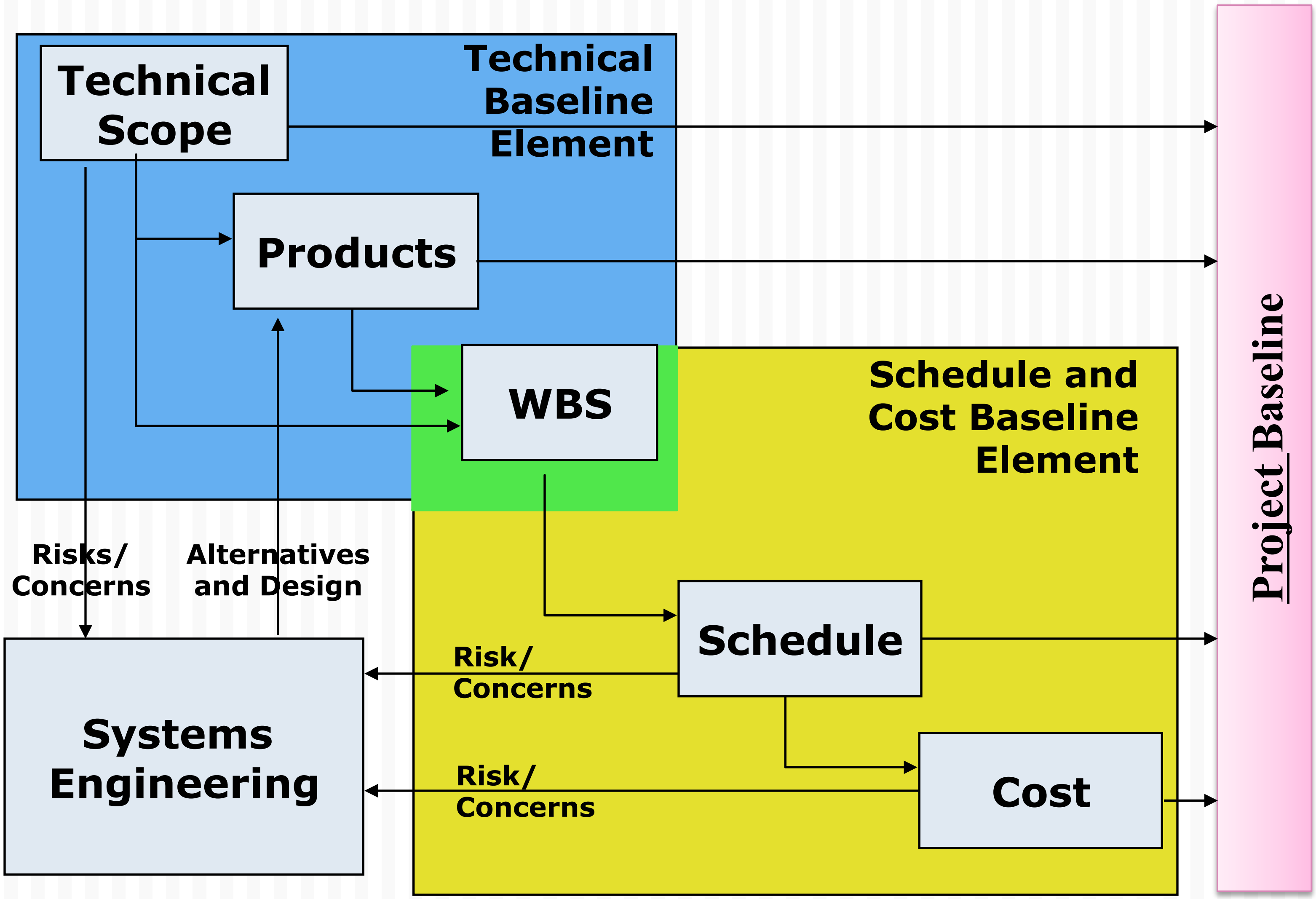
… Requires Adaptable Understanding Of "Process"

System Thinking Principles

- Expect the unexpected
- Approach the right problem
- Fully know the problem and all its aspects
- Understand the next higher problem
- Make system-level decisions
- Use criteria based on next-higher-level needs
- Consider the long-term impacts



Systems Engr & Project Mgmt



Difficult to Standardize

SE Categories	ANSI/EIA-632	IEEE-1220	ISO-15288	CMMI	MIL-STD-499C
Mission/purpose definition	Not included in scope	▪ Define customer expectations (Req Anlys)	▪ Stakeholder needs definition	▪ Develop customer requirements (Req Devlp)	Not included in scope
Requirements management	System Design ▪ Requirements definition	▪ Requirements analysis	▪ Requirements analysis	▪ Req'ments development ▪ Requirements mgmt	▪ System requirements analysis and validation
System architecting	System Design ▪ Solution definition	▪ Synthesis	▪ Architectural design ▪ System life cycle mgmt	▪ Technical solution	▪ System product technical req'ments anlys/validation ▪ Design or physical solution representation
System implementation	Product Realization ▪ Implementation ▪ Transition to Use	Not included in scope	▪ Implementation ▪ Integration ▪ Transition	▪ Product integration	Not included in scope
Technical analysis	Technical Evaluation ▪ Systems analysis	▪ Functional analysis ▪ Requirements trade studies and assessments ▪ Functional trade studies and assessments ▪ Design trade studies and assessments	▪ Requirements analysis	▪ Measurement and analysis	▪ Functional analysis, allocations and validation ▪ Assessments of system effectiveness, cost, schedule, and risk ▪ Tradeoff analyses

Technical management/ leadership	Technical Mgmt
	▪ Planning
	▪ Assessment
	▪ Control
		▪ Technical mgmt
		▪ Track analysis data
		▪ Track requirements and design changes
		▪ Track performance
		  ▪ Against project plans
		  ▪ Against technical plans
		▪ Track product metrics
		▪ Update specifications
		▪ Update architectures
		▪ Update plans
		▪ Maintain database
			▪ Planning
			▪ Assessment
			▪ Control
			▪ Decision mgmt
			▪ Configuration mgmt
			▪ Acquisition
			▪ Supply
			▪ Resource mgmt
			▪ Risk mgmt
				▪ Project planning
				▪ Project monitoring & control
				▪ Supplier agreement mgmt
				▪ Process and product quality assurance
				▪ Configuration mgmt
				▪ Integrated project mgmt
				▪ Decision analysis and resolution
				▪ Quantitative project mgmt
				▪ Risk mgmt
					▪ Planning
					▪ Monitoring
					▪ Decision making, control, and baseline maintenance
					▪ Risk mgmt
					▪ Baseline change control and maintenance
					▪ Interface mgmt
					▪ Data mgmt
					▪ Technical mgmt of subcontractors/vendors
					▪ Technical reviews/audits

Verification & validation	Technical Evaluation ▪ Requirements validation ▪ System verification ▪ End products validation	▪ Requirement verification ▪ Functional verification ▪ Design verification	▪ Verification ▪ Validation	▪ Verification ▪ Validation	▪ Design or physical solution verification and validation

Amagasaki Railway Crash

- Derailment in Amagasaki, Apr 05
  - Seven-car train
  - Front two cars into apartment complex parking garage
  - 106 dead, 555 injured
- Japanese train system based on punctuality
  - Commuters rely on timing of cross-station transfers
  - Punctuality vastly important – 6 sec delay is concern
  - Drivers face pay penalties, humiliating “training”
- Failure investigation
  - Driver overran previous station, lost 90 sec to back up
  - Train speed was 100 kph in area zoned for 70 kph
  - Stones on the track

Systems Engineering and Complexity

Systems Engineering is the engineering of complexity!

…and it always has been

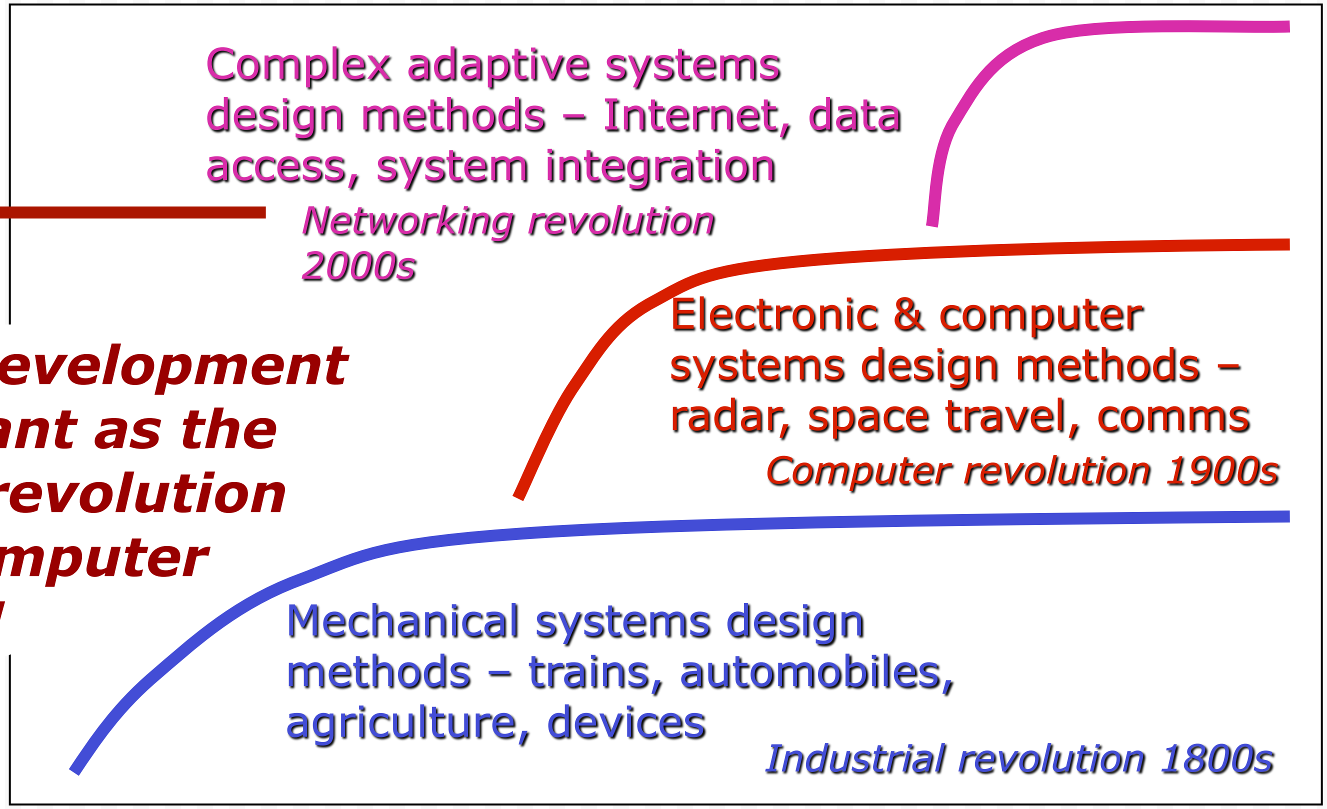
Today, SoS and complexity are affecting Systems Engineering:

- New methods appearing
- Old methods used in new ways

Paradigm Shifts in Systems Engineering

Complexity

Nexus of development as significant as the industrial revolution and the computer revolution!

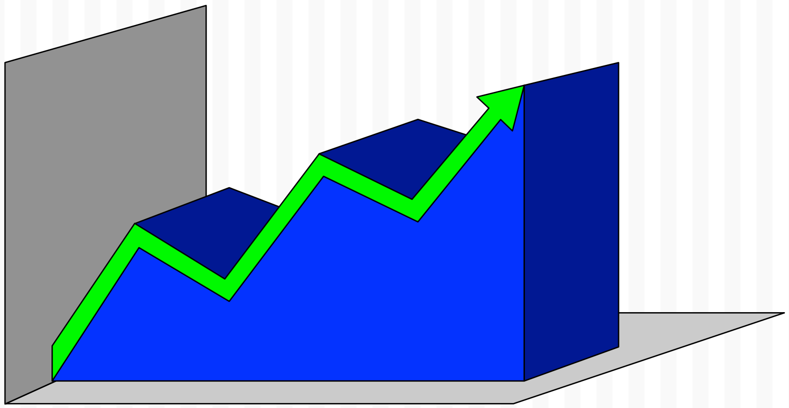


Historical Time

- Each paradigm fuels a rapid growth and then stagnates as it tries to handle more complex products

Systems Engineering Is More Than a Process

- **It is as much a way of thinking and operating as it is a process.**
- **It is a road map; a pathway to help us achieve our goals.**
- **The process assists, but it is not a substitute for getting the job done.**



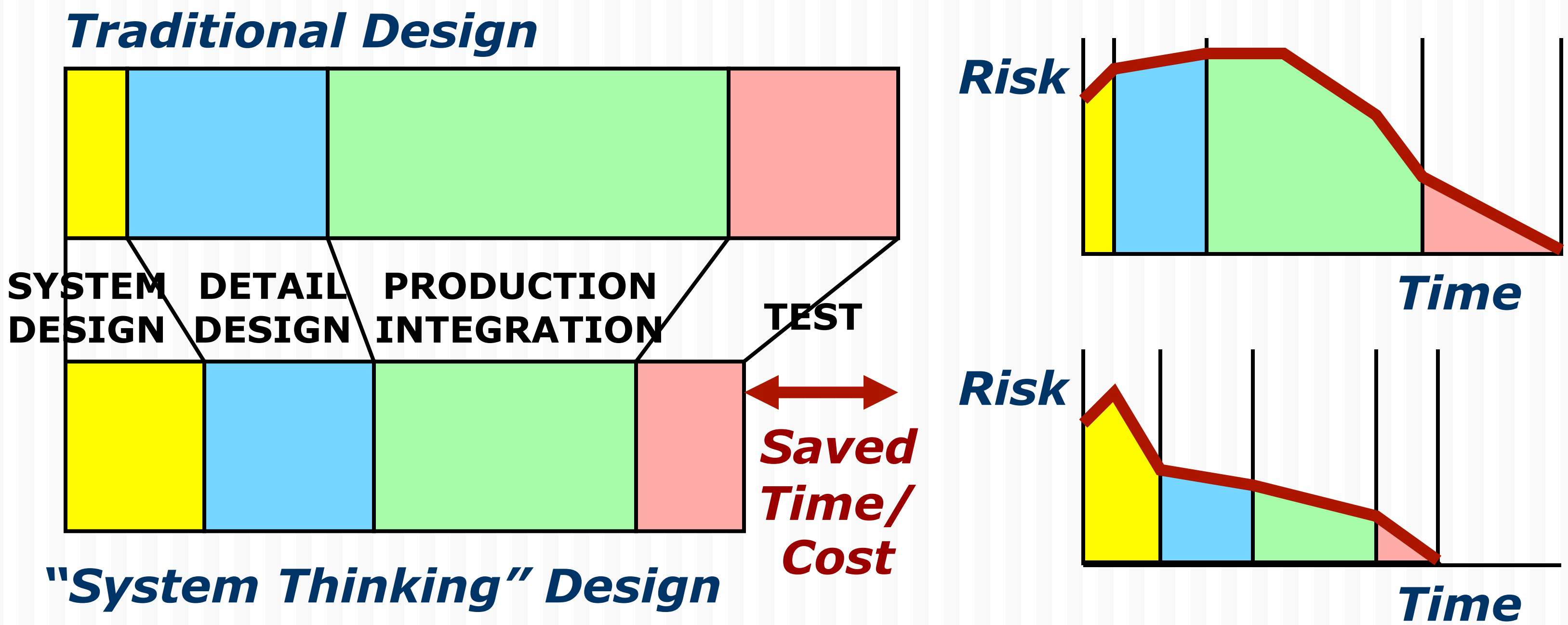
SE-ROI Project

Methodology

Industry support

Heuristic Claim of SE

- **Better systems engineering leads to**
  - **Better system quality/value**
  - **Lower cost**
  - **Shorter schedule**



Not Known: How Much Is Enough?

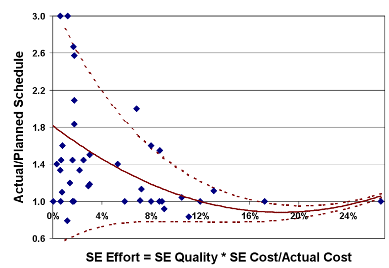
SE-ROI Project

Interviews

- **Just-completed programs**
- **Key PM/SE/Admin**
- **Translate program data into project structure**

- *Program characterization*
- *Program success data*
- *SE data (hours, quality, methods)*

Statistical correlation



Desired Results

1. **Statistical correlation of SE practices with project success**
2. **Leading indicators**
3. **Identification of good SE practices**

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Basic Demographics

Characteristic	ValueSE Data Set	SE-ROI Data Set
Number of organizations	Unknown	16
Number of data points	44	48
Funding method	Unknown	39 contracted, 9 amortized
Program total cost	\$1.1M - \$5.6B Median \$42.5M	\$600K - \$1.8B Median \$14.4M
Cost compliance	(0.8):1 – (3.0):1 Median (1.2):1	(0.6):1 – (10):1 Median (1.0):1
Development schedule	2.8 mo. – 144 mo. Median 43 mo.	2 mo. – 120 mo. Median 35 mo.
Schedule compliance	(0.8):1 – (4.0):1 Median (1.2):1	(0.3):1 – (2.5):1 Median (1.1):1
Percent of program used in systems engineering effort, by cost	0.1% - 27% Median 5.8%	0.1% - 80% Median 17.4%
Subjective assessment of systems engineering quality (1 poor to 10 world class)	Values of 1 to 10 Median 5	Values of 1 to 10 Median 7

SE-ROI Results: Primary Relationships

SE effort correlates with 3 of 4 success measures

Optimum SE effort 14.4% of total development cost

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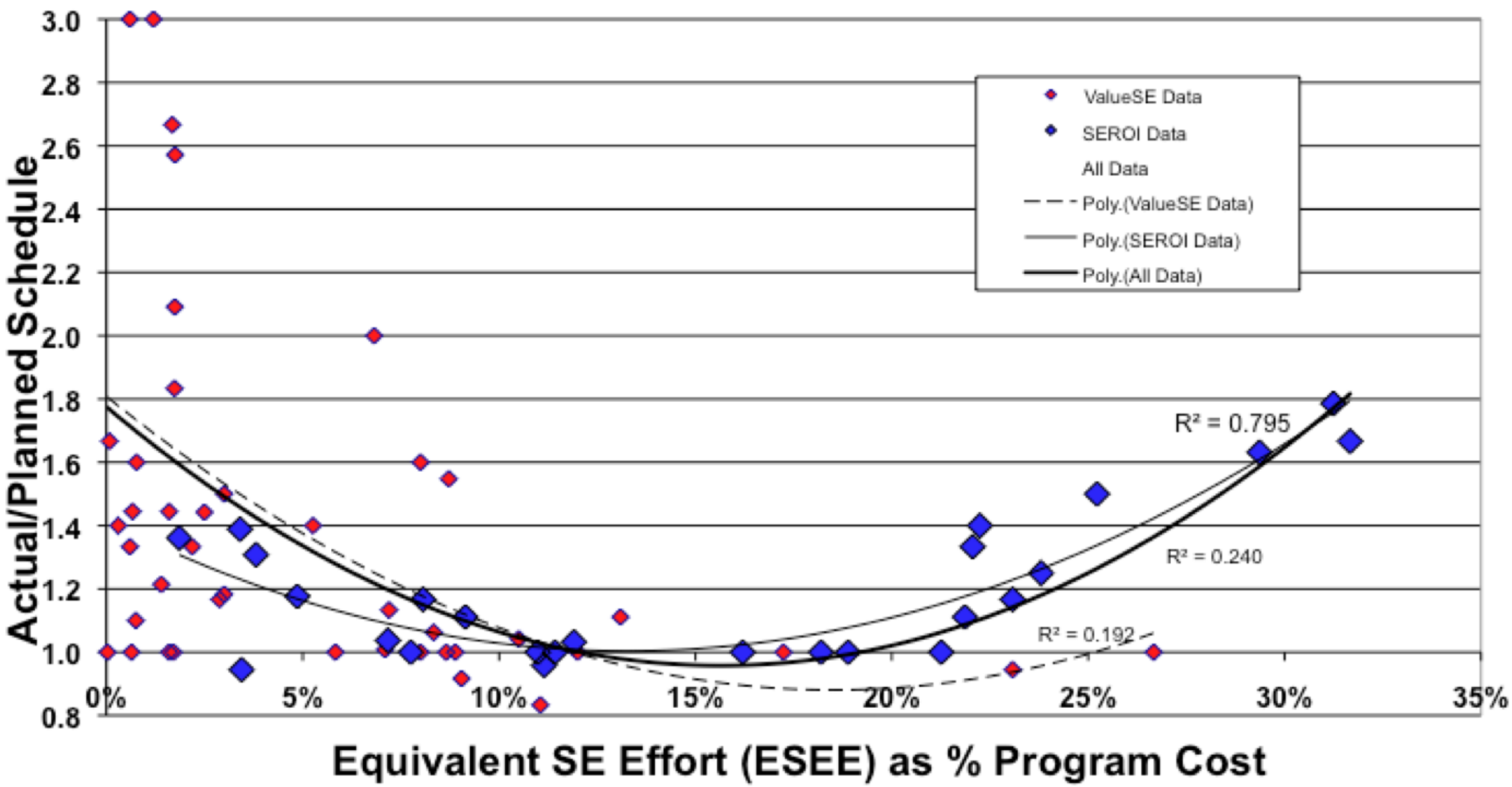
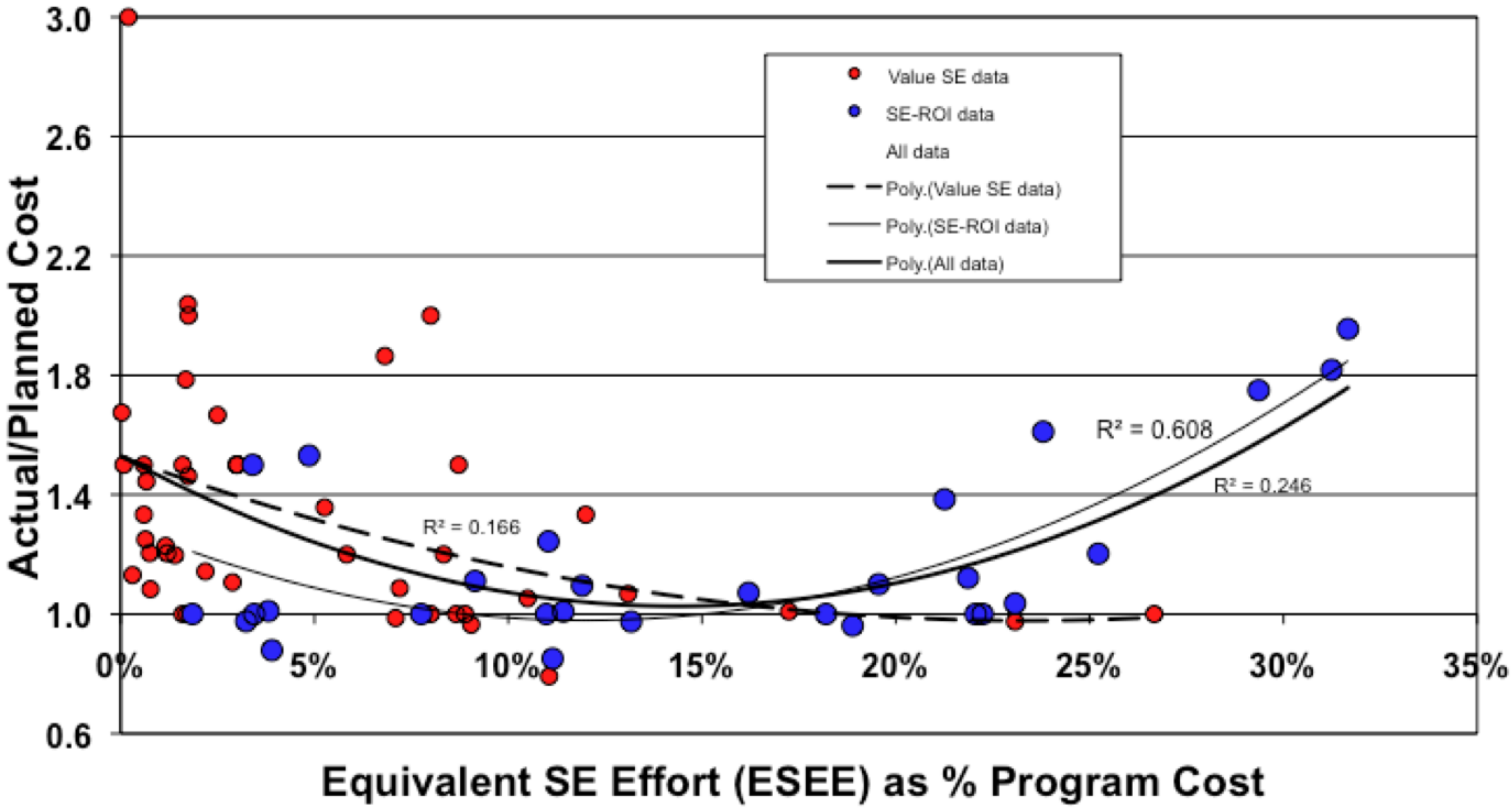
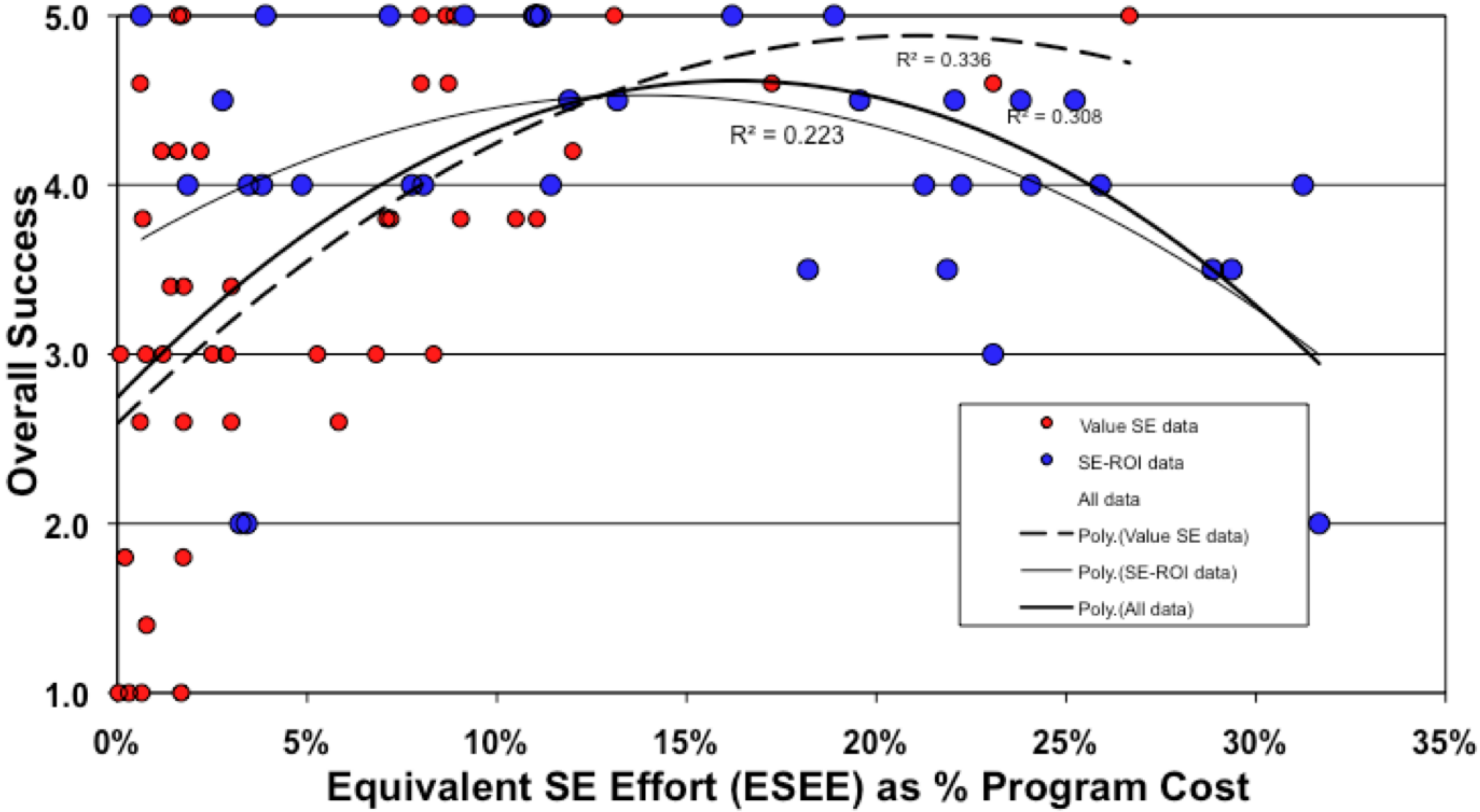
Schedule vs. SE Effort



Cost vs. SE Effort



Overall Success vs. SE Effort



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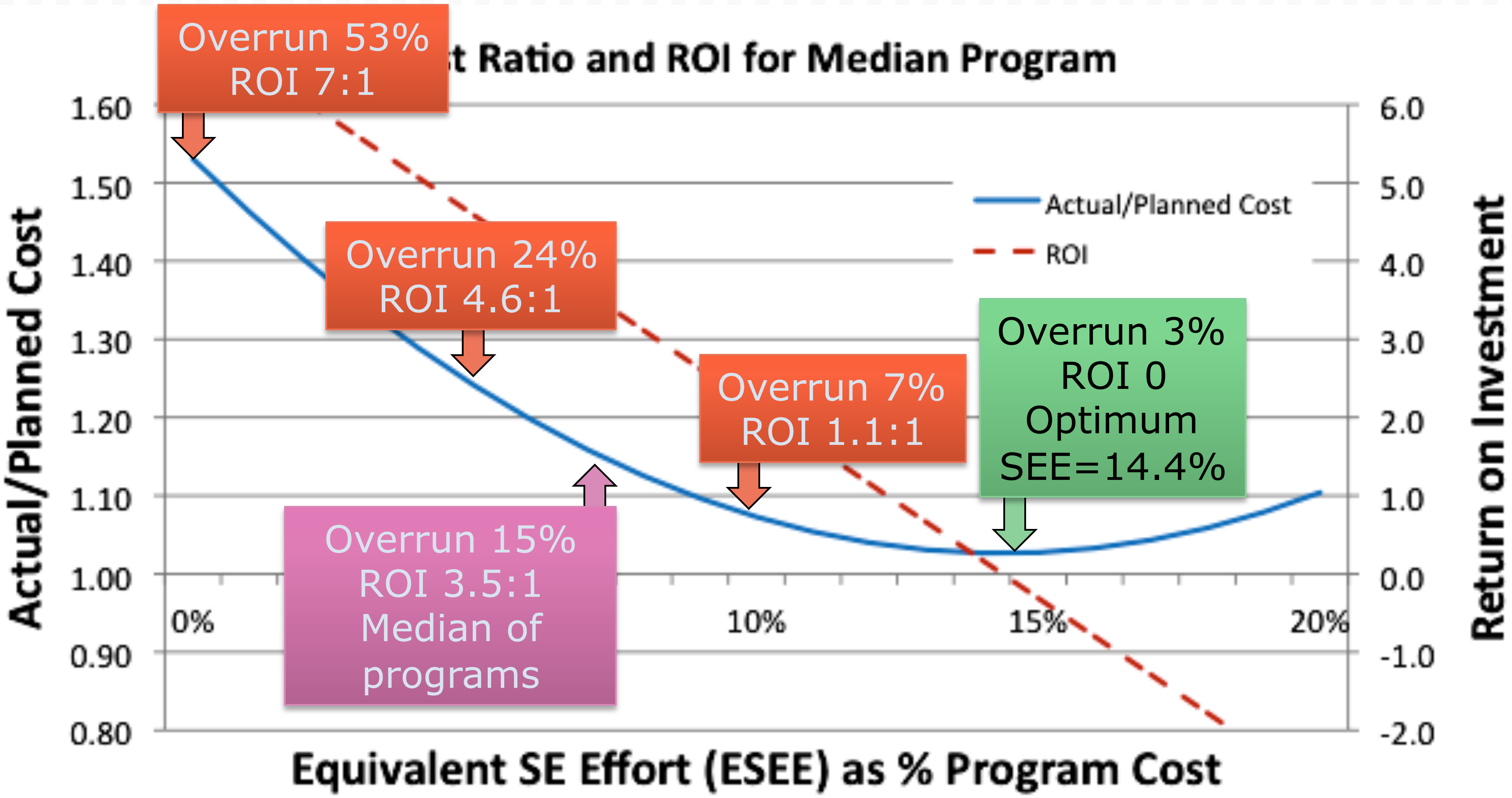
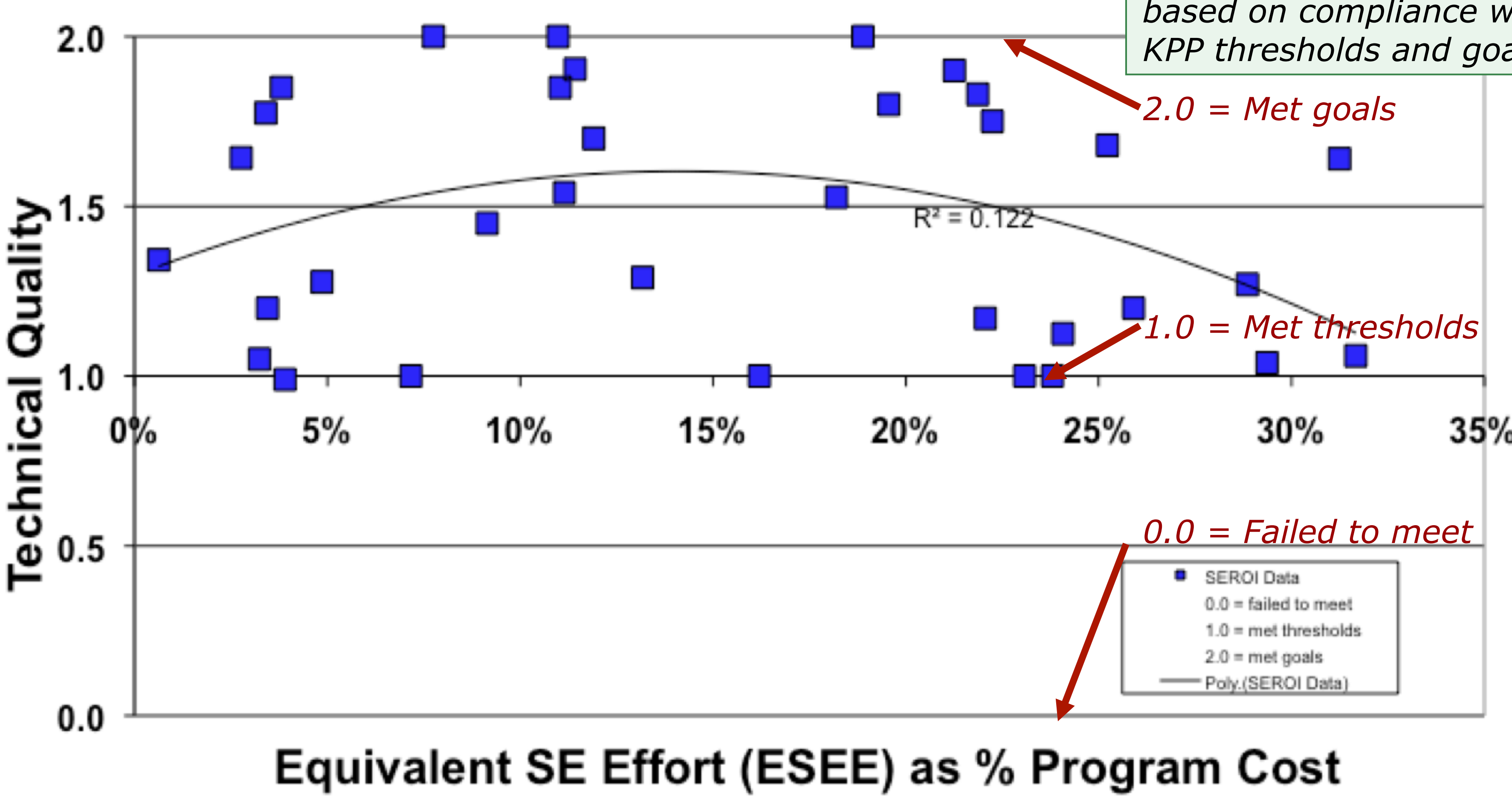
Return on Investment



Technical Quality vs. SE Effort

"Technical Quality" is based on compliance with KPP thresholds and goals



SE-ROI Results: Eight SE Activities

- Most SE activities correlate w/ cost, schedule, overall
- None correlate w/ quality
- Successful programs use front-end; poor programs use back-end

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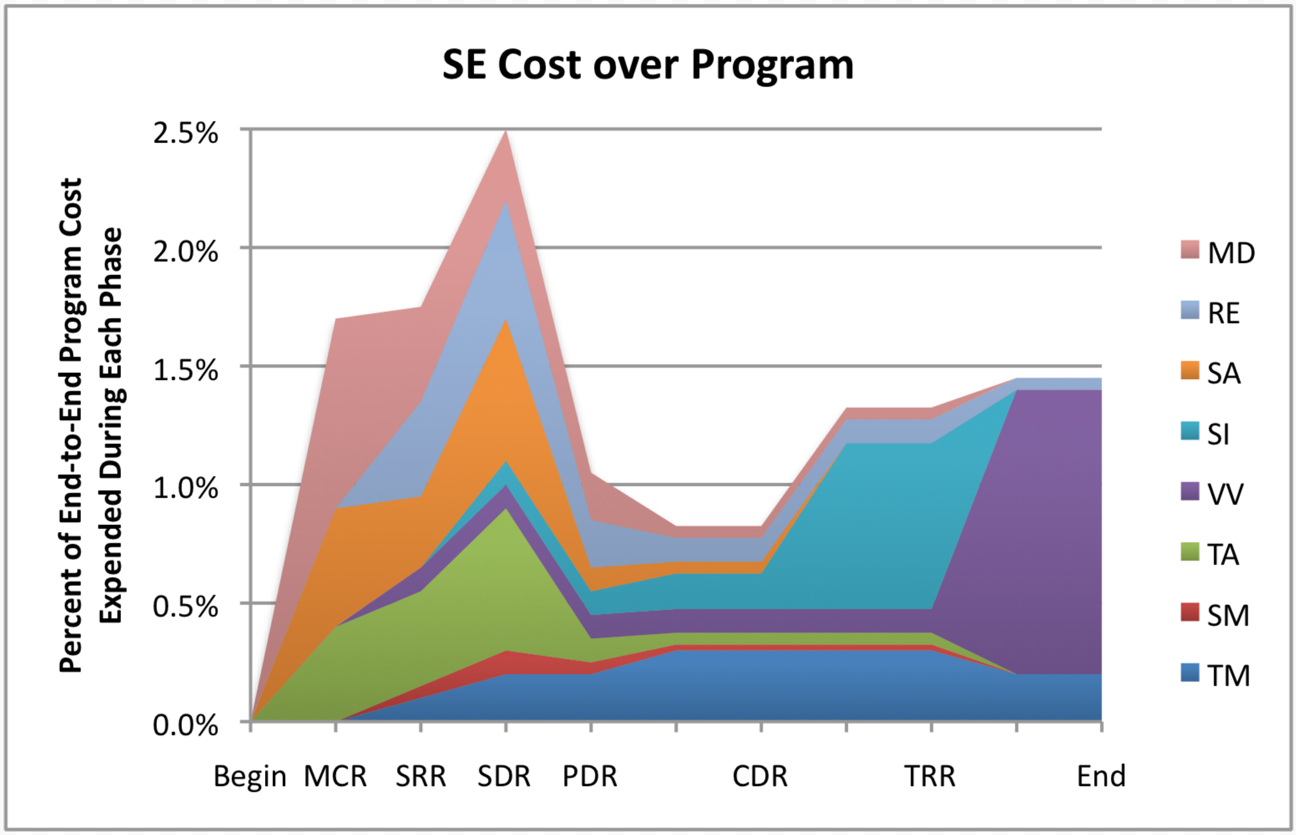
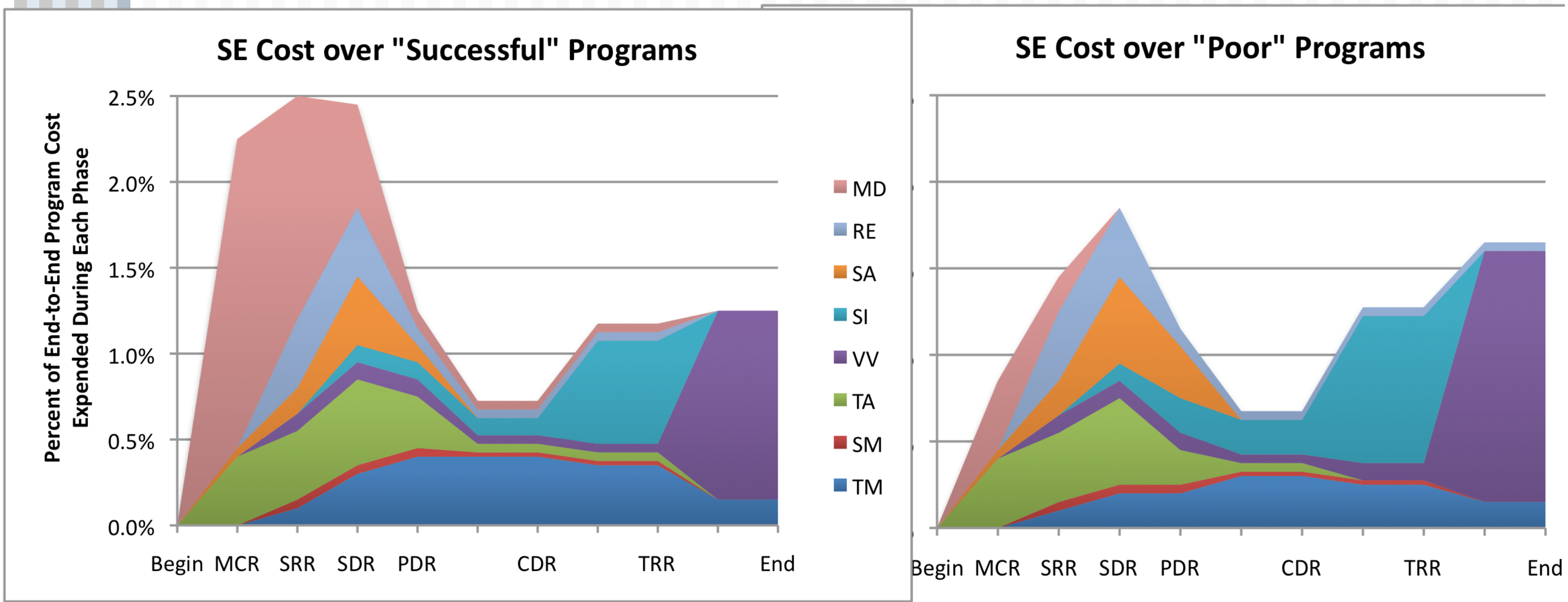
Breakout by SE Activities

MD Mission/Purpose Definition
RE Requirements Engineering
SA System Architecting
SI System Integration
VV Verification & Validation
TA Technical Analysis
SM Scope Management
TM Technical Leadership/Management



Breakout by Success

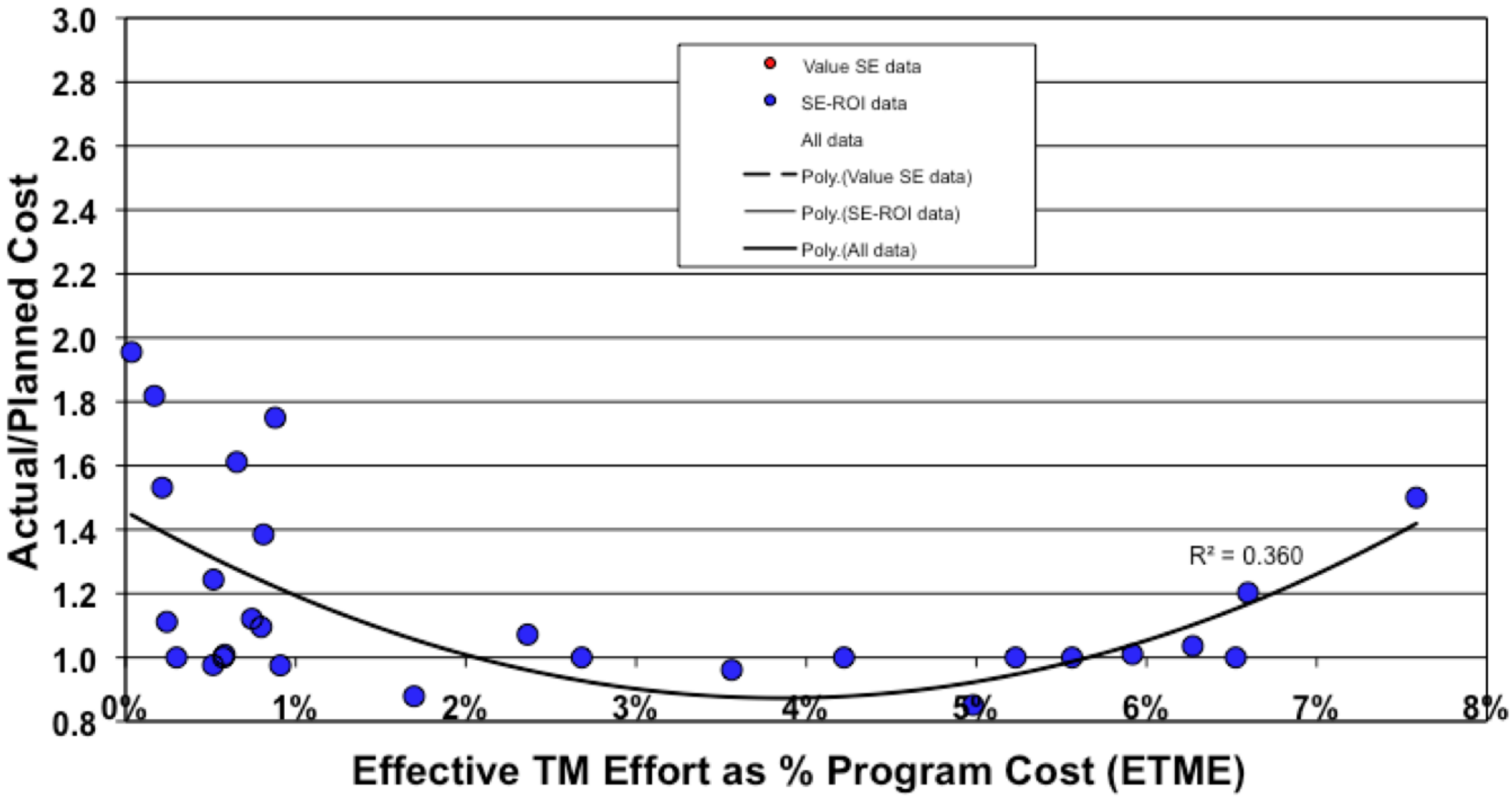


Successful *(~on cost)*
- More mission/purpose defn
- More tech leadership/mgmt
- More Systems Engineering

Poor *(overran cost)*
- More system integration
- More verif & valid
- Less Systems Engineering

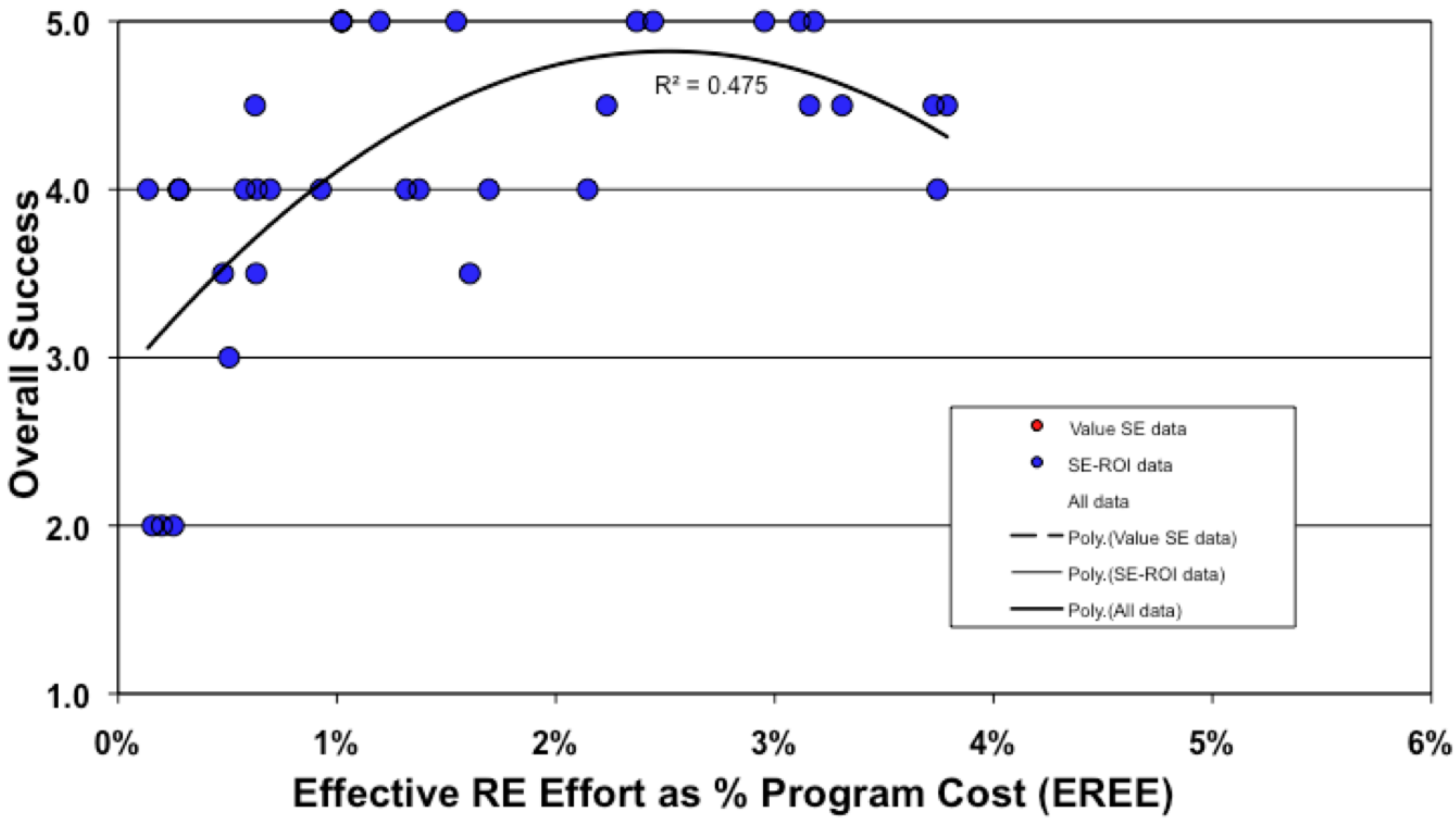
Typical Data:

Cost vs. Tech Lead'ship/Mgmt



Typical Data:

Overall Success vs. Reqs Engr



Effect of SE Activities

Activity	Code	Quantifiable Correlation Exists With			
		Cost Compliance	**Schedule Compliance**	**Overall Success**	**Technical Quality**
Total Systems Engineering Effort	SE	Yes	Yes	Yes	Perhaps
Mission/Purpose Definition Effort	MD	Yes	Yes	No	No
Requirements Engineering Effort	RE	Yes	Yes	Yes	No
System Architecting Effort	SA	Yes	Yes	Yes	No
System Integration Effort	SI	Yes	Yes	Yes	No
Verification & Validation Effort	VV	Yes	Yes	No	No
Technical Analysis Effort	TA	Yes	Yes	Perhaps	No
Scope Management Effort	SM	Yes	No	Yes	No
Technical Management/ Leadership Effort	TM	Yes	Yes	Yes	No

SE-ROI Results: Right-Sizing SE

Parametric sizing of SE to optimize success

Optimum Levels, Median Program

Activity	Code	Optimum	Median of data
Total Systems Engineering	SE	**14.4%**	8.5%
Mission/Purpose Definition	MD	**1.3%**	1.6%
Requirements Engineering	RE	**2.0%**	0.8%
System Architecting	SA	**3.9%**	1.4%
System Integration	SI	**2.8%**	1.5%
Verification & Validation	VV	**2.4%**	2.0%
Technical Analysis	TA	**1.8%**	1.3%
Scope Management	SM	**1.4%**	0.3%
Technical Leadership/Management	TM	**3.9%**	1.9%

Honour, EC, "Systems Engineering Return on Investment, UniSA'12

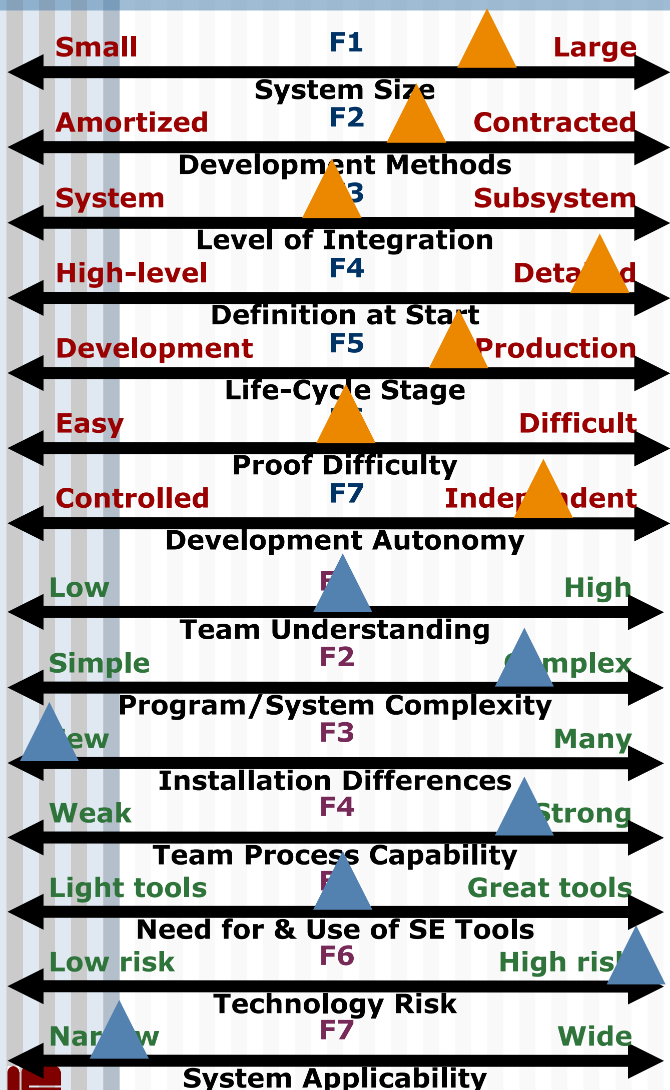
Estimating optimum SE

- Start with median optimum values
- Estimate 14 characterization parameters
- Adjust SE level for characterization
  - Apply weights to median SE level to determine "should-be" level

$$OSEE = OSEE_0 * \prod_{j=1...14} \left(\frac{PP_j}{.5} \right)^{\frac{+Weight_j}{100}}$$

- Result is optimum SE effort levels for a program of these characteristics

Example: “Space System”



	Median Optimum	Adjustment	Program Optimum
MD	1.3%	0.38	0.5%
RE	2.0%	0.50	1.0%
SA	3.9%	0.69	2.7%
SI	2.8%	0.50	1.4%
VV	2.4%	0.68	1.9%
TA	1.8%	0.79	1.3%
SM	1.4%	0.72	1.2%
TM	3.9%	1.41	5.5%
SE	**14.4%**	**1.08**	**15.6%**

Summary

Bottom Line

- Systems Engineering is the engineering of complexity
  - More than a process – a way of thinking
- SE target: 14% of a development project
- Better programs use more mission definition, more technical leadership
  - Better cost/schedule control, stakeholder success
- Today's process-based SE does not correlate with system technical quality

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Questions?

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