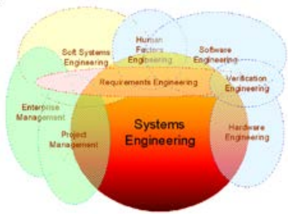
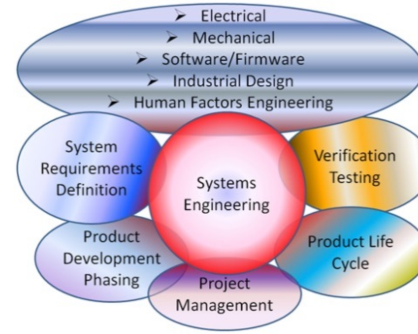
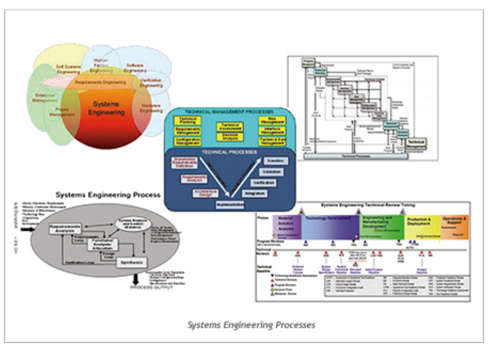




Systems Engineering Return on Investment



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Appropriate Questions to Ask

What do you mean by “Systems Engineering”? Define Your Terms.

What does your organization mean by “Systems Engineering”? What is their formal definition? What/who is included? What is the organizational model?

What is your organization’s definition of a successful program/good program performance?

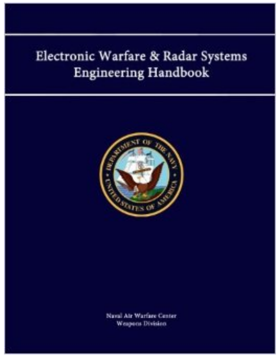
What is your definition of good/adequate/mature/complete Systems Engineering?

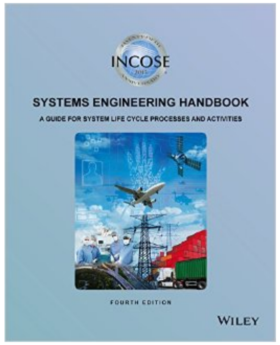
Once we know what we are researching, how do you know if a program is doing ***good*** systems engineering?

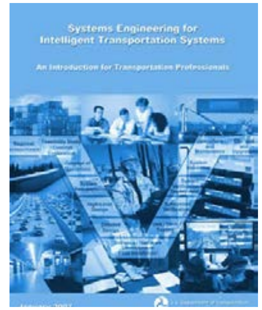
What has been the data on Systems Engineering ROI so far?

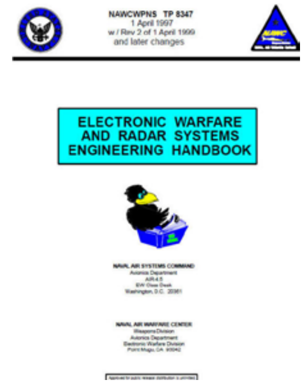
Once we know what we are researching and historical data , then how do we show the value of ***your*** Systems Engineering?

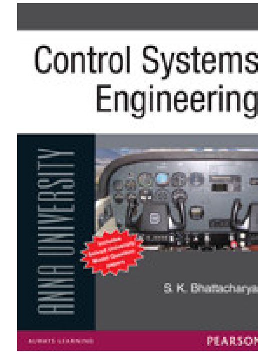
What do you mean by “Systems Engineering”

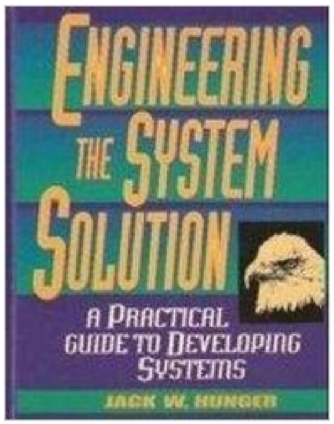


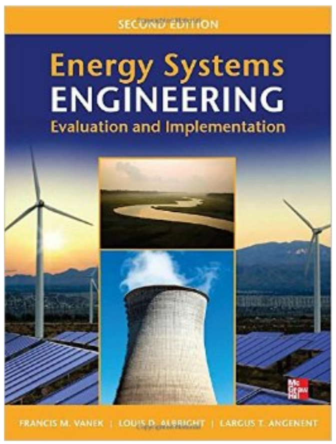


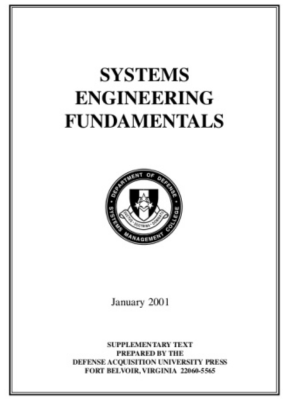


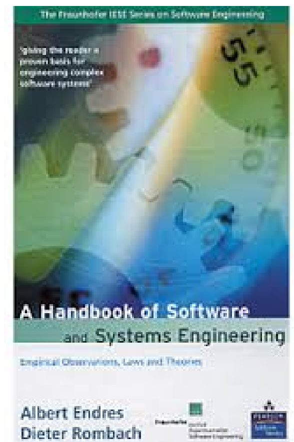


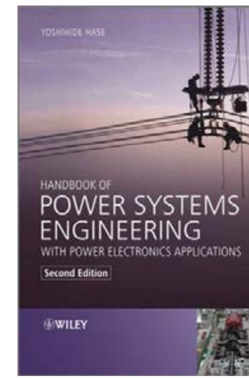


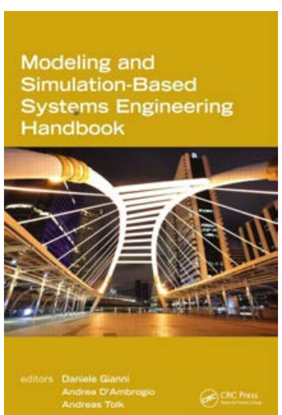


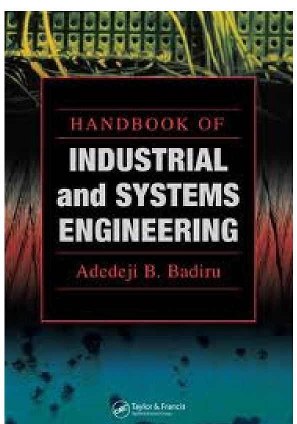


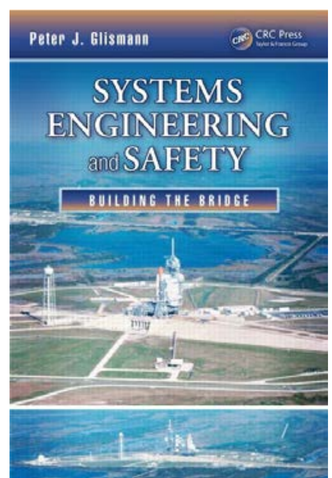


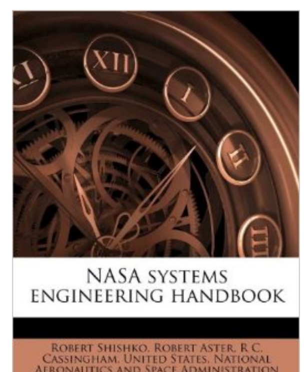


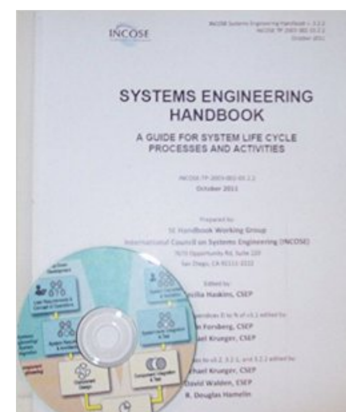












What do you mean by "Systems Engineering"? Define Your Terms.

Systems engineering - **An inter-disciplinary approach and a means** to enable the realization of successful systems. Systems engineering requires a broad knowledge, a mindset that keeps the big picture in mind, a facilitator, and a skilled conductor of a team

Systems Engineering is **an interdisciplinary approach and means** to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

What is Systems Engineering?

Systems engineering is a **multidisciplinary (technical and business) approach** with the purpose of leading the engineering of a complex interrelated set of components working together toward a common purpose. The scope of the practice ranges from concept to production and acquisition to post-deployment support (operation). The objective of system engineering is to be involved through all phases of a system to ensure that the end product has the optimal cost-effective solution. Cost effective solution is the tradeoff of performance against cost, schedule and risk often leading to dilemmas in the field of system engineering requiring trade-off studies to be conducted.

Systems engineering is a **methodical, disciplined approach** for the design, realization, technical management, operations, and retirement of a system. A "system" is a construct or collection of different elements that together produce results not obtainable by the elements alone.

Systems engineering is **an interdisciplinary field of engineering** that focuses on how to design and manage complex engineering systems over their life cycles. Issues such as requirements engineering, reliability, logistics, coordination of different teams, testing and evaluation, maintainability and many other disciplines necessary for successful system development, design, implementation, and ultimate decommission become more difficult when dealing with large or complex projects. Systems engineering deals with work-processes, optimization methods, and risk management tools in such projects. It overlaps technical and human-centered disciplines such as control engineering, industrial engineering, software engineering, organizational studies, and project management. Systems engineering ensures that all likely aspects of a project or system are considered, and integrated into a whole.

Defining Systems Engineering

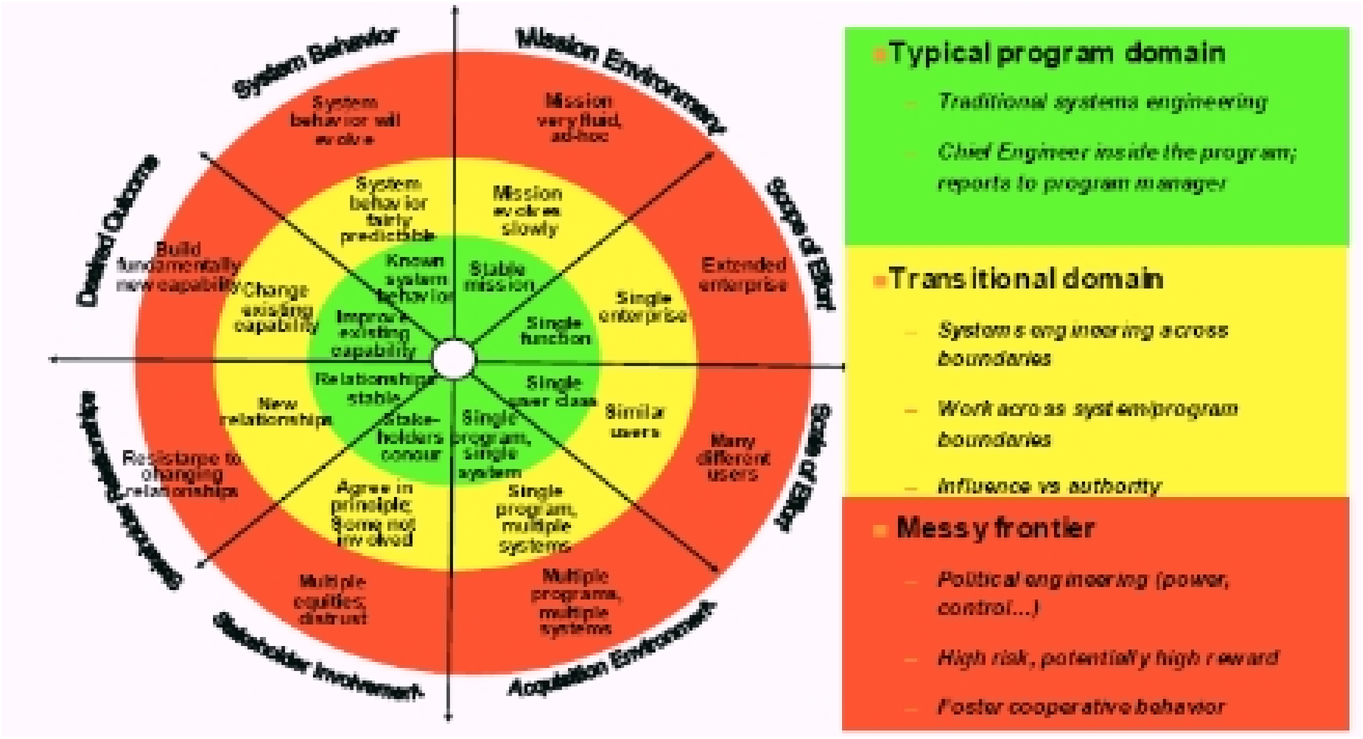
- **INCOSE Definition**:
  - An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. **13 Processes in Handbook**

- "Big Picture" perspective – ***<u>Focus is basically the difference</u>***

- **Includes**
  - System Definition (mission/operational requirements, system requirements, architectural design)
  - Interfaces and interactions
  - Engineering management
  - Analysis, simulation, modeling, prototyping
  - Integration, verification, and validation

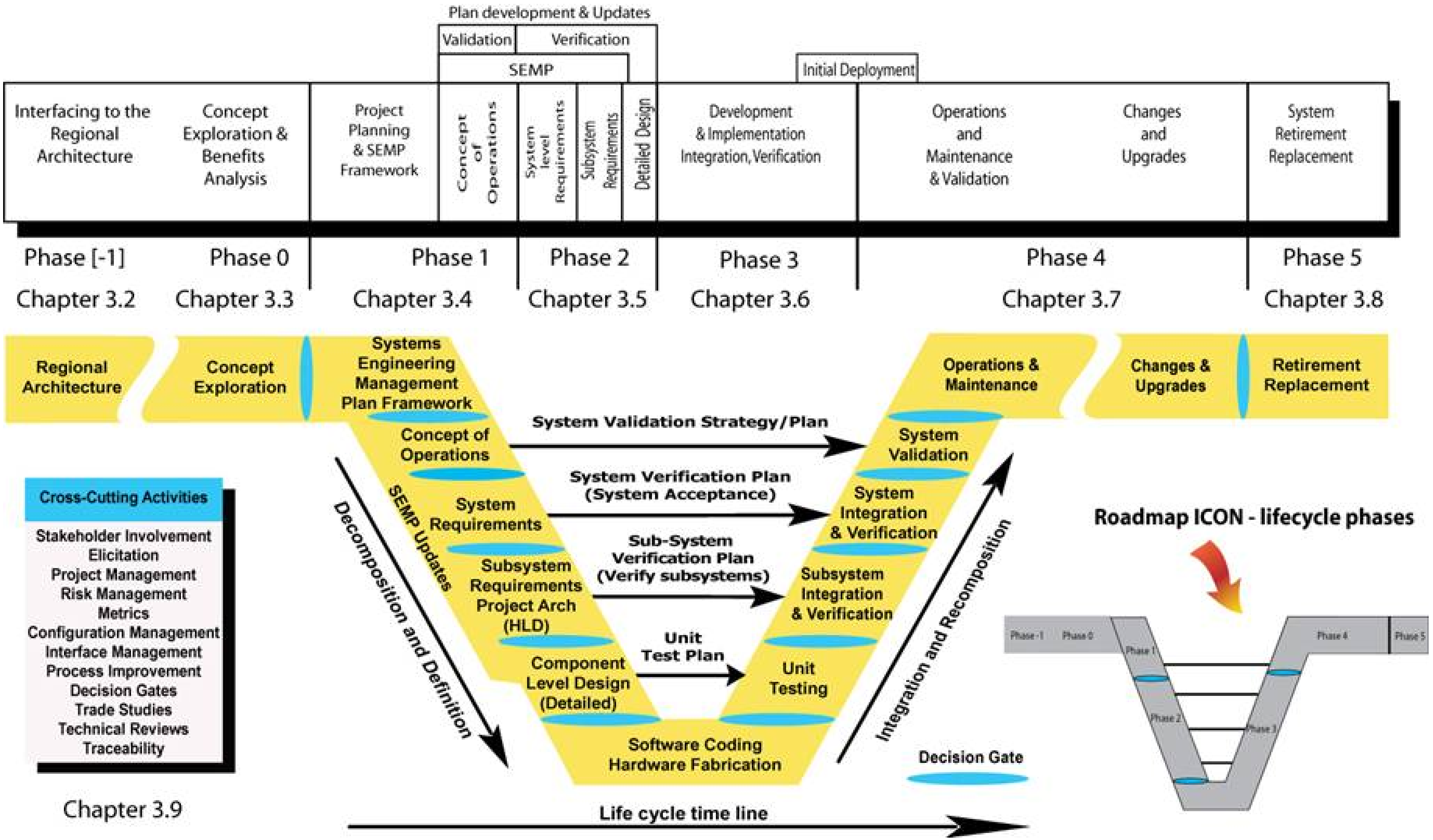
- **Standards that focus on SE activities and tasks**
  - ISO/IEC 15288, System Life Cycle Processes
  - EIA 632, Engineering of a System
  - IEEE Std 1220, Application and Mgt of the SE Process
  - MIL-STD-499, System Engineering Management
  - CMMI SE

Does the Domain Impact the SE Definition/Use?



This picture is extracted from the document "System of Systems Systems Engineering Guide: Considerations for Systems Engineering in a System of Systems Environment," Dec 22, 2006, For System of System Pilot Project, Version 0.9, Director, Systems and Software Engineering Deputy Under Secretary of Defense (Acquisition and Technology) Office of the Under Secretary of Defense (Acquisition, Technology and Logistics).

Does the Life Cycle Phase Impact the SE Definition/Use?



Does Standard Use Impact Systems Engineering Definition?

Systems Engineering Effort Categories Evident in the Standards

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 engineering	System Design ▪ Requirements definition	▪ Requirements analysis ▪ Track requirements and design changes	▪ 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	▪ Select product-component solutions (Tech sol'n) ▪ Develop the design (Tech sol'n)	▪ 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	▪ Implement the product design (Tech sol'n) ▪ Product integration	Not included in scope
Technical analysis	Technical Evaluation ▪ Systems analysis	▪ Functional analysis ▪ Requirements trade studies ▪ Functional trade studies ▪ Design trade studies	▪ Requirements analysis	▪ Decision analysis and resolution	▪ 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 performance – project plans, tech plans ▪ Track product metrics ▪ Update specifications ▪ Update architectures ▪ Update plans ▪ Maintain database	▪ Planning ▪ Assessment ▪ Control ▪ Decision mgmt ▪ Configuration mgmt ▪ Resource mgmt ▪ Risk mgmt	▪ Project planning ▪ Project monitoring & control ▪ Measurement and analysis ▪ Process and product quality assurance ▪ Configuration mgmt ▪ Integrated project mgmt ▪ 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 reviews/audits
Scope management	Acquisition & Supply ▪ Supply ▪ Acquisition	Not included in scope	▪ Acquisition ▪ Supply	▪ Supplier agreement mgmt	▪ Technical mgmt of subcontractors/vendors
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
In the standard, but not in agreement with other standards			▪ Operation ▪ Disposal ▪ Enterprise mgmt ▪ Investment mgmt ▪ Quality mgmt	▪ Organ'l process focus ▪ Organ'l process definition ▪ Organ'l training ▪ Organ'l process perf ▪ Causal analysis/resolution ▪ Organ'l innov/deploymnt	▪ Lessons learned and continuous improvement

What Is Your Organization's Definition of a Successful Program/Good Program Performance?

Program success may be defined as a program that is completed • on time • on budget • within specifications

Each of these three attributes can be evaluated as a binary value (e.g., true, false). Successful programs produce "true" values for all three attributes. However, the reality is somewhat more complicated. None of these attributes is truly binary; each is actually a continuum. Furthermore, all three attributes are interrelated. A program can often satisfy more of its specifications at an increase in cost. A program can often be completed more quickly if relief is granted on some of the specifications. These interrelationships raise questions such as the following:

- Is a program that is 10% over budget, but is completed six months early, more or less successful than a program that is completed on budget but six months late?
- Is a program that is completed on time and on budget and meets 95% of its specifications more or less successful than a program that meets all of its specifications but is 20% over budget and three months late?

Often the answers to these questions are specific to the program itself. For some programs, on-time performance is more important than other factors (e.g., an upgrade to a weapons system needed on the battlefield immediately). For some programs compliance to specifications is paramount (e.g., satisfaction of safety criteria for a medical device). For other programs on-budget performance is most critical. **For meaningful use in determining SE effectiveness and ROI, the assessment of program performance must achieve a consistent combination of the assessment of all three of these performance elements.**

For the SE effectiveness and ROI, program performance is defined as the amalgam of three characteristics:

1. Cost performance—the satisfaction of cost and budgetary constraints

2. Schedule performance—the satisfaction of intermediate and final time constraints

3. Technical performance—the satisfaction of technical and quality requirements

What Is Your Definition of Good/Adequate/Mature/Complete Systems Engineering?

Using all of the 13 INCOSE defined SE processes?

Using all of the 13 INCOSE defined processes **EFFECTIVELY**?

Using some of the SE processes? Using them Effectively?

Using one of the processes?

Using Systems Thinking but not specific processes?

Having Plans, Processes and Procedures formally defined (and maybe used)? Effectively?

Being certified to ISO or high CMMI levels?

Having your Programs be **<u>successful</u>**?

Value of Systems Engineering

Why Measure Systems Engineering?
Systems engineering and other disciplines execute processes in order to produce their products (e.g., requirements, plans, specifications, designs, analyses, hardware, software, integration activities, and verification and validation procedures). **The primary measurement for any feedback control system is based on measures of the output products that provide information.**

Systems engineering activities use the information generated to modify the application of SE processes to improve the quality, timeliness, efficiency, and effectiveness of the products and supporting processes (analogous to the application of statistical process control on manufactured products). Measures can focus on both work products and work processes. In addition, there are 'progress' measures, for which measurement takes place at various points/events as the project activities are executed. The data is collected and analyzed as the SE processes are performed to provide timely insight.

Value of Systems Engineering

Performance Assessment Measures

Typical **measures for assessing SE performance** of an enterprise include the following:

1. Effectiveness of SE process (***Define effective?***)
2. Ability to mobilize the right resources at the right time for a new program or new program phase
3. Quality of SE process outputs (***Who judges this?)***
4. Timeliness of SE process outputs (***Based on what schedule?)***
5. **SE added value to program** (***Does the program need added value?***)
6. **System added value to end users** (***Do the users want added value?)***
7. **SE added value to organization** ***(Does the organization need added value?)***
8. Organization's SE capability development ***(What is required?)***
9. Individuals' SE competence development ***(Who monitors and certifies?)***
10. Resource utilization, current and forecast
11. Productivity of systems engineers ***(??????)***
12. Deployment and **consistent** usage of tools and methods

SEBOK - http://sebokwiki.org/wiki/Assessing_Systems_Engineering_Performance_of_Business_and_Enterprises

Assessing Systems Engineering Performance in Business or Enterprise

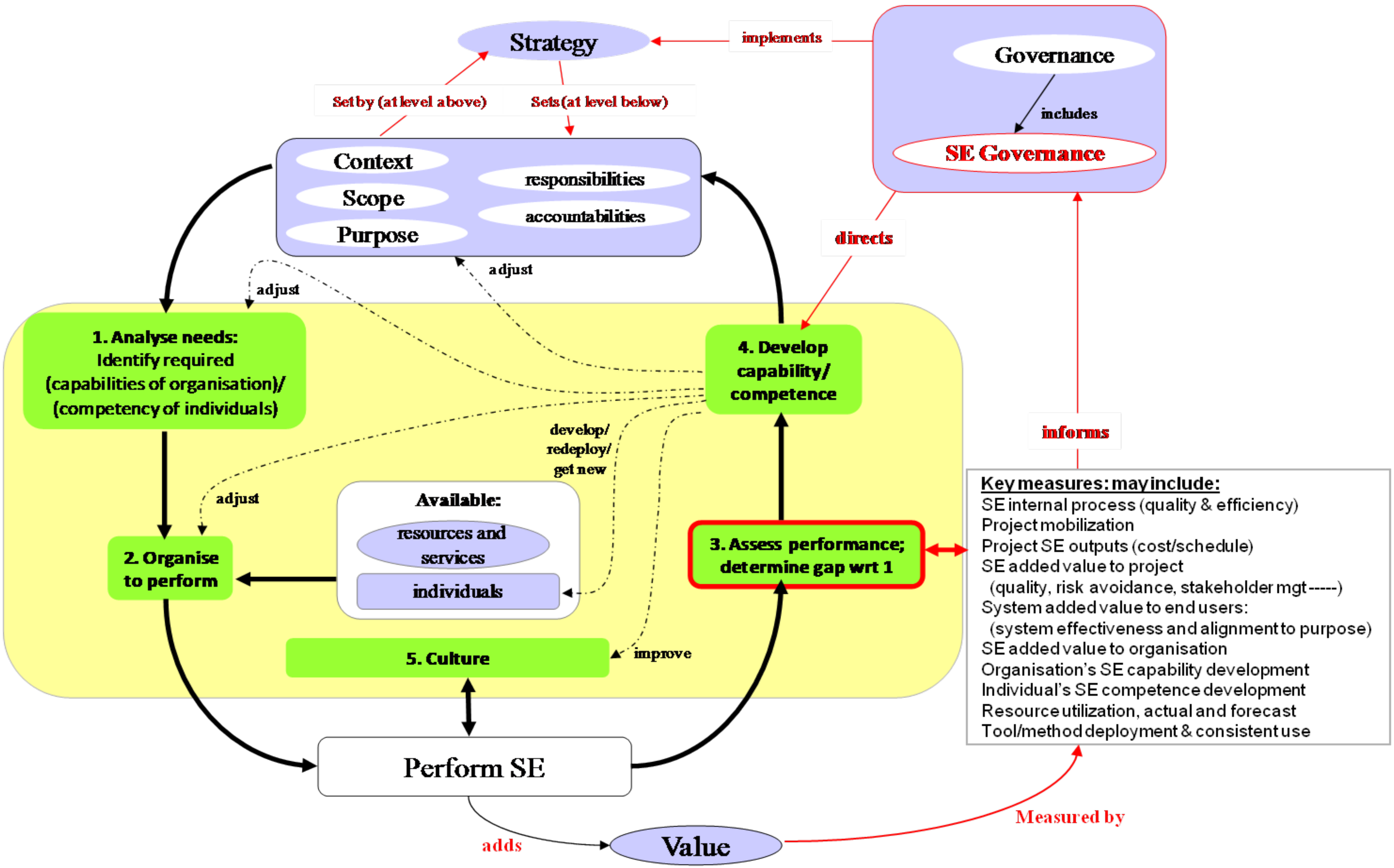


Figure 1 shows one way in which appropriate measures inform enterprise level governance and drive an improvement cycle such as the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) model.

Systems Engineering Leading Indicators

From INCOSE MWG

Thirteen leading indicators defined by SE measurement experts

Developed by a working group sponsored by Lean Aerospace Initiative (LAI) collaboratively with INCOSE, PSM, and SEARI

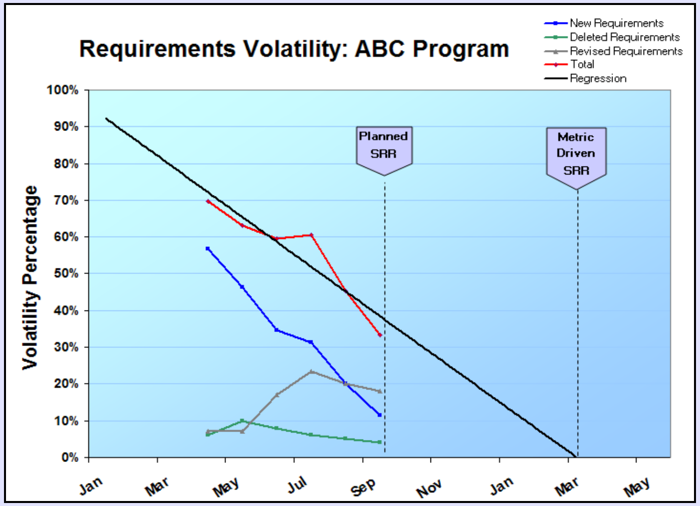
- Supported by 5 leading defense companies and 3 DoD services

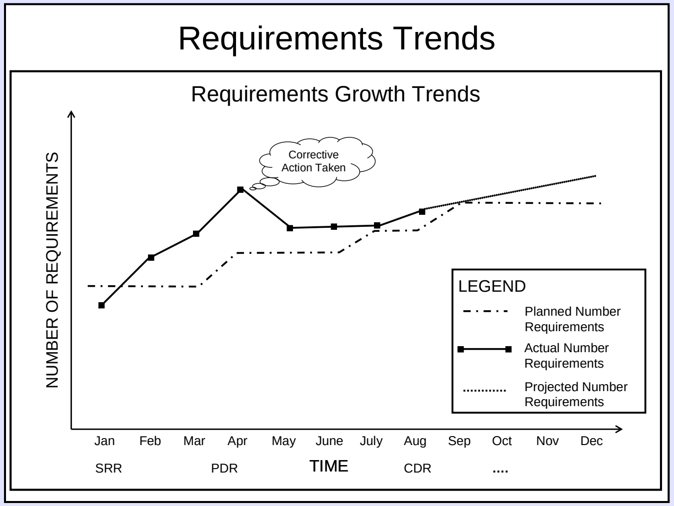
Beta guide released December 2005; Version 1.0 released in June 2007

Additional leading indicators being defined for future update

Several companies tailoring the guide for internal use

Objective: Develop a set of SE Leading Indicators to assess if program is performing SE effectively, and to enhance proactive decision making





List of Indicators

- Requirements **Trends** (growth; correct and complete)
- System Definition Change Backlog **Trends** (cycle time, growth)
- Interface **Trends** (growth; correct and complete)
- Requirements Validation Rate **Trends** (at each level of development)
- Requirements Verification **Trends** (at each level of development)
- Work Product Approval **Trends**
  - Internal Approval (approval by program review authority)
  - External Approval (approval by the customer review authority)
- Review Action Closure **Trends** (plan vs actual for closure of actions over time)
- Technology Maturity **Trends** (planned vs actual over time)
  - New Technology (applicability to programs)
  - Older Technology (obsolescence)
- Risk Exposure **Trends** (planned vs actual over time)
- Risk Handling **Trends** (plan vs actual for closure of actions over time)
- SE Staffing and Skills **Trends**: # of SE staff per staffing plan (level or skill - planned vs. actual)
- Process Compliance **Trends**
- Technical Measurement **Trends**: MOEs (or KPPs), MOPs, TPMs, and margins

Current set has 13 Leading Indicators

Systems Engineering Return on Investment

To use this metric effectively it is important to understand the overall formula, the definition of each of the terms in the equation, and the steps to take for using it in the decision making processes.
In general, the formula would look something like this:

Simple ROI = (Gain from Investment – Cost of Investment) / (Cost of Investment)

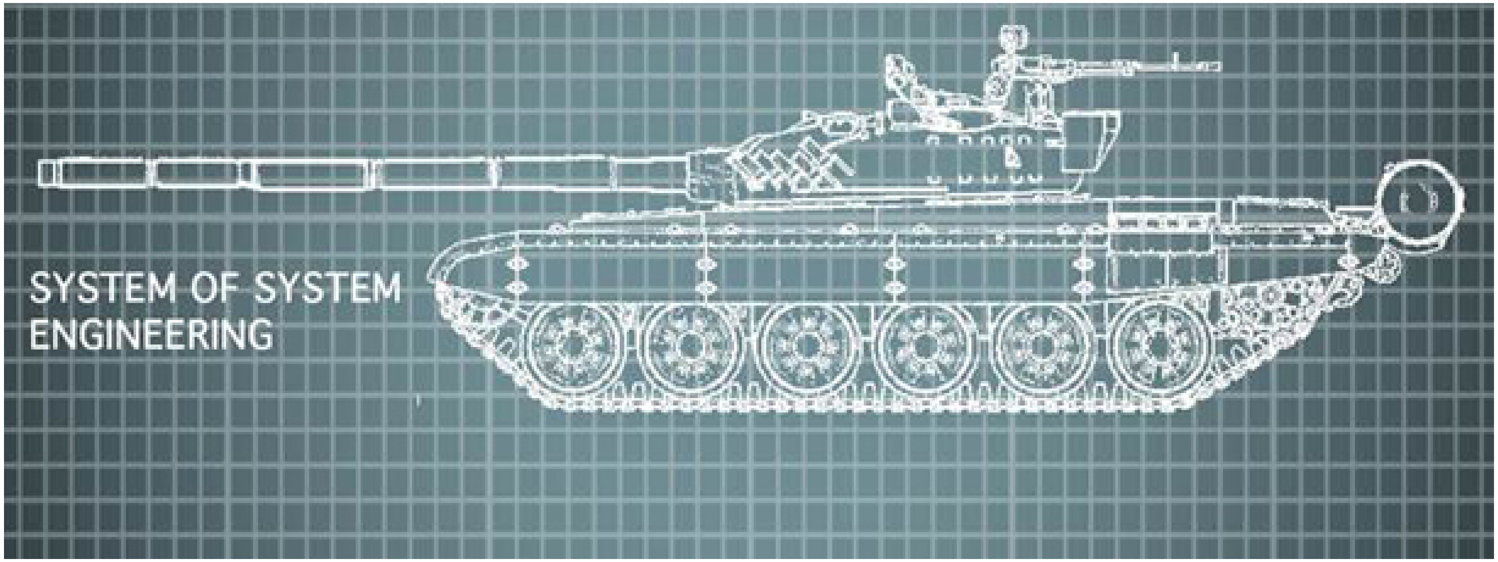
Although each organization may have a different flavor of the ROI metric, meaning differences in the formula could include:

- Evaluating ROI over different time periods
- Using Rate of Return instead of ROI, where Rate of Return puts the return in terms of Compound Annual Growth Rate (CAGR)
- Using different Hurdle Rates (minimum ROI or Rate of Return required by a company to make an investment)

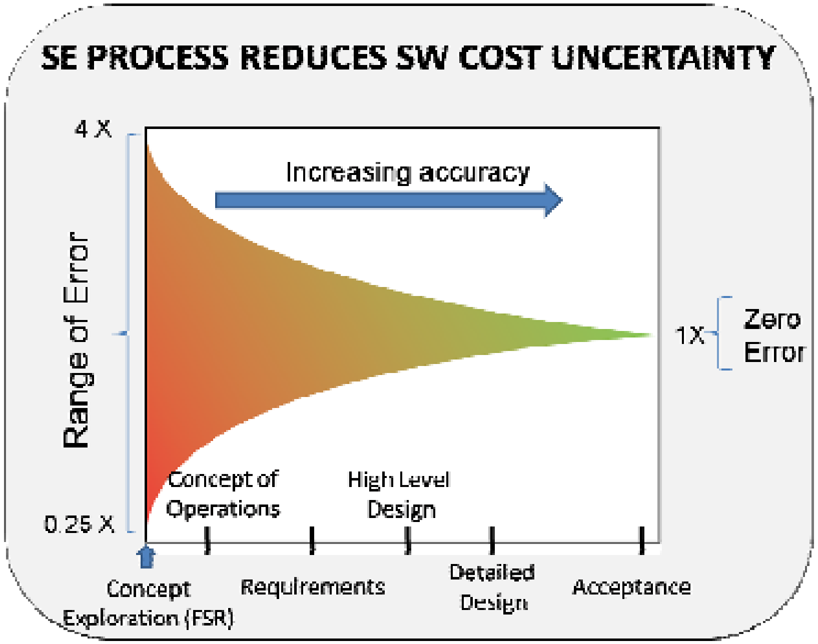
Systems Engineering Return on Investment

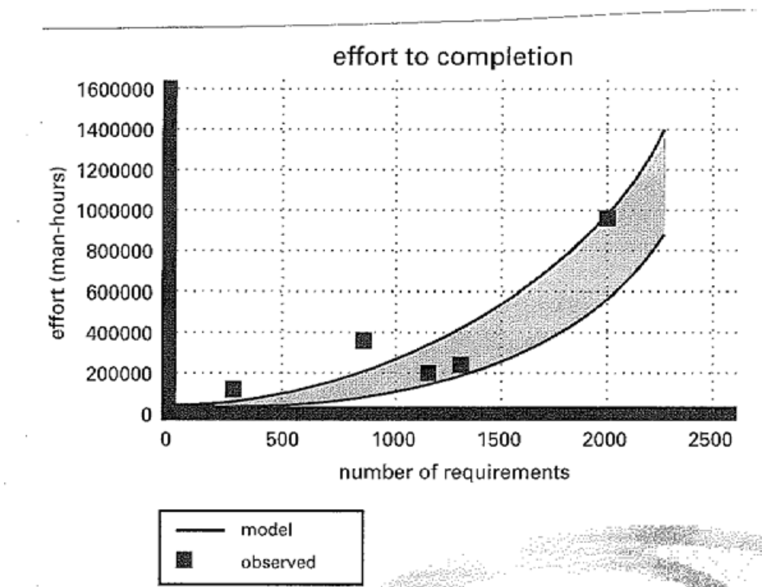
Quote from Presentation by Mr. Peter Nolte Deputy Director, Major Program Support , Office of the Deputy Assistant Secretary of Defense for Systems Engineering - October 2012

"Systems Engineering is Critical to Program Success"



Systems Engineering Return on Investment



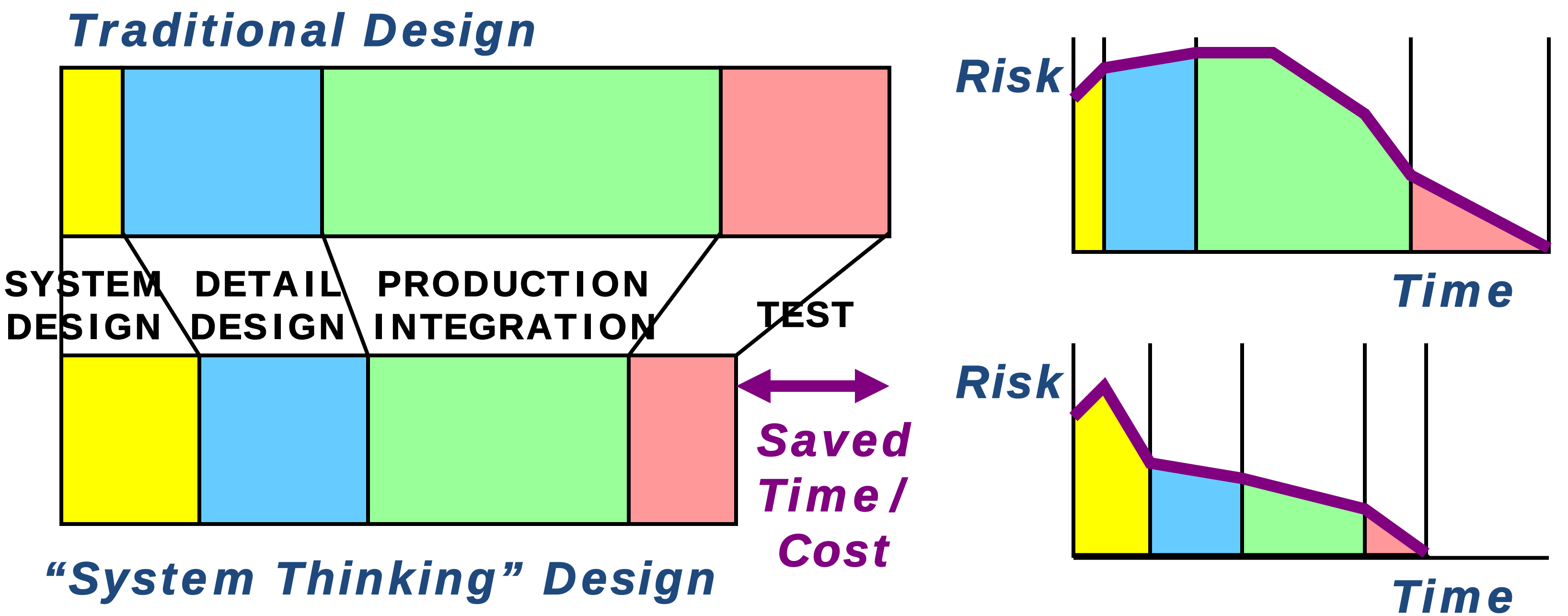


Cost of Fixing Errors in Your Project

	systems cost factors
requirements	x1 (reference)
design	x5
build	x12
test	x40
operations	x250

Heuristic Claim of SE Value

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



Need to Know: How Much Is Enough?

Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Systems Engineering Return on Investment

The Return on Investment (ROI) for SE effort can be as high as 7:1 for programs expending little to no SE effort. For programs expending a median level of SE effort, the ROI is 3.5:1.

Return on Investment
INCOSE data shows that a spend of 8% of project budget on effective Systems Engineering - much less than you typically spend on fixing errors - reduces the average cost of projects by >20%, and increases your likelihood of delivering on time by 50%.

There is an optimum amount of systems engineering effort for best program success. For a program of median characterization parameters, that optimum is 14.4% of the total program cost.

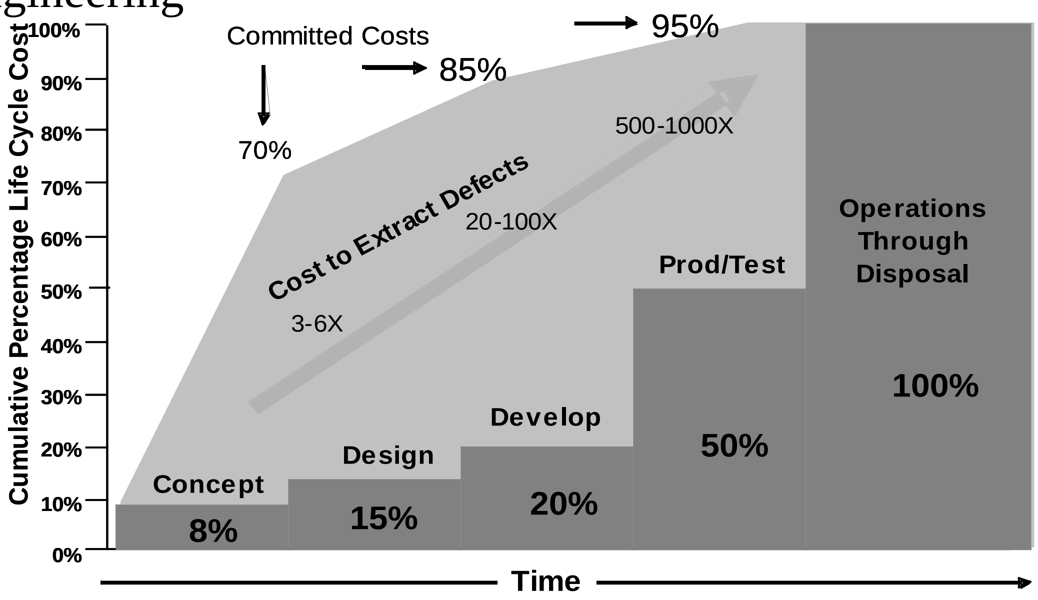
UK Downey principles (DERA 1996), defined since the 1960s, in which 15% of the total project costs should be expended during systems definition ‘to engender speedier, more coherent and interactive processes.’ This number is also contained in MOD (1999).

Programs typically use less systems engineering effort than is optimum for best success.

Systems Engineering Return on Investment

The historical and current data have shown that the following are strong trends when SE is used consistently and efficiently:

1. Better/more systems engineering correlates to shorter schedules by 40% or more, even in the face of greater complexity.
2. Better/more systems engineering correlates to lower development costs, by 30% or more.
3. Greater Technical Leadership/Management correlates with lower Schedule overruns,
4. Greater Verification/Validation correlates with lower Cost overruns,
5. Greater Requirements Engineering correlates with better Overall Mission Success.
6. Unsuccessful programs, in comparison to successful programs, expended:
   a) 50% less effort in mission definition
   b) 33% less effort in requirements engineering
   c) 33% less effort in scope management
   d) 40% more effort in systems architecting
   e) 60% more effort in implementation/integration
   f) 25% more effort in verification/validation

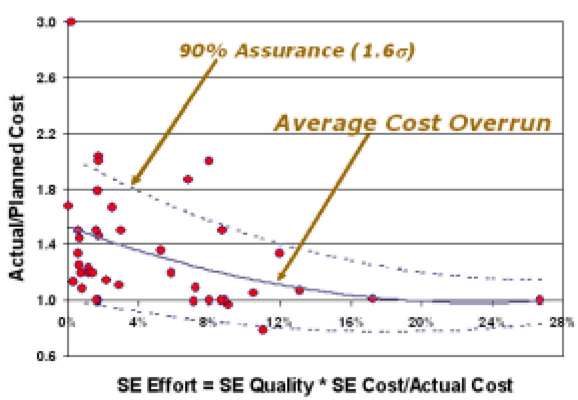


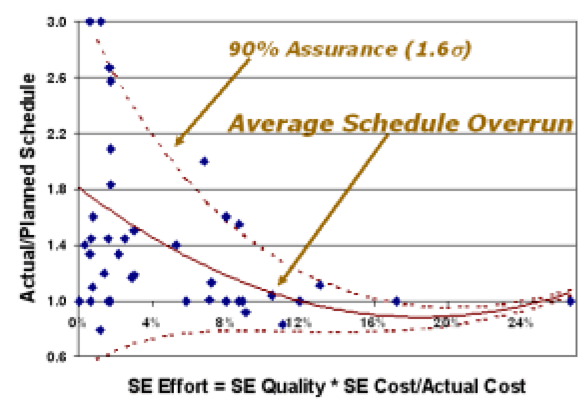
Systems Engineering Return on Investment

What Did We Know Before?

Results from the preliminary (2004) Value of Systems Engineering work:

- ***Better technical leadership correlates to program success.*** *[Ancona 1990, Miller 2000]*
- ***Better/more systems engineering correlates to shorter schedules by 40% or more, even in the face of greater complexity.*** *[Franz 1995, Honour 2004]*
- ***Better/more systems engineering correlates to lower development costs, by 30% or more.*** *[Gruhl 1992, Barker 2003, Kludze 2004, Honour 2004]*
- ***Optimum level of systems engineering is about 15% of a total development program.*** *[Gruhl 1992, Honour 2004]*
- ***Programs typically operate at about 6% systems engineering.*** *[Kludze 2004, Honour 2004]*
- ***Parametric cost estimation of systems engineering is possible.*** *[Valerdi 2004]*
- ***SE practices correlate to program success.*** *[Gamgee 2006]*





Systems Engineering Return on Investment

Unsuccessful projects, in comparison to successful projects, expended:
50% less effort in mission definition

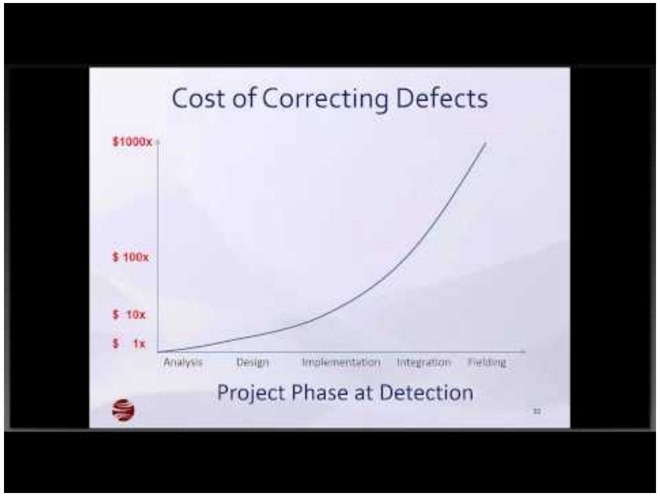
33% less effort in requirements engineering

33% less effort in scope management

40% more effort in systems architecting

60% more effort in implementation/integration

25% more effort in verification/validation



Successful Projects Spent More Up Front

Kerri Polidore, Systems Engineer, ARDEC-Systems Engineering Infrastructure

Major Results SE ROI

- Strong quantified relationship between SE and program success *(Correlation r^2 80%)*
  - Optimum SE activity for median programs is 14.4% of program cost
  - Median programs use much less than the optimum; ROI to re-allocate additional effort into SE is 3.5:1
  - Relationships also exist for eight subordinate SE activities such as Mission/Purpose Definition, Requirements Engineering, System Architecting, etc.
- No correlation between SE activities and technical quality
  - Over-emphasis on requirements defeats creating better systems, even within the same cost and schedule
- Estimation method now available for optimum program SE effort, based on program characteristics
  - Characteristics modify the optimum between ~8% and ~19%
  - Optimizing level of Technical Leadership/Management simultaneously optimizes cost, schedule, and stakeholder acceptance.

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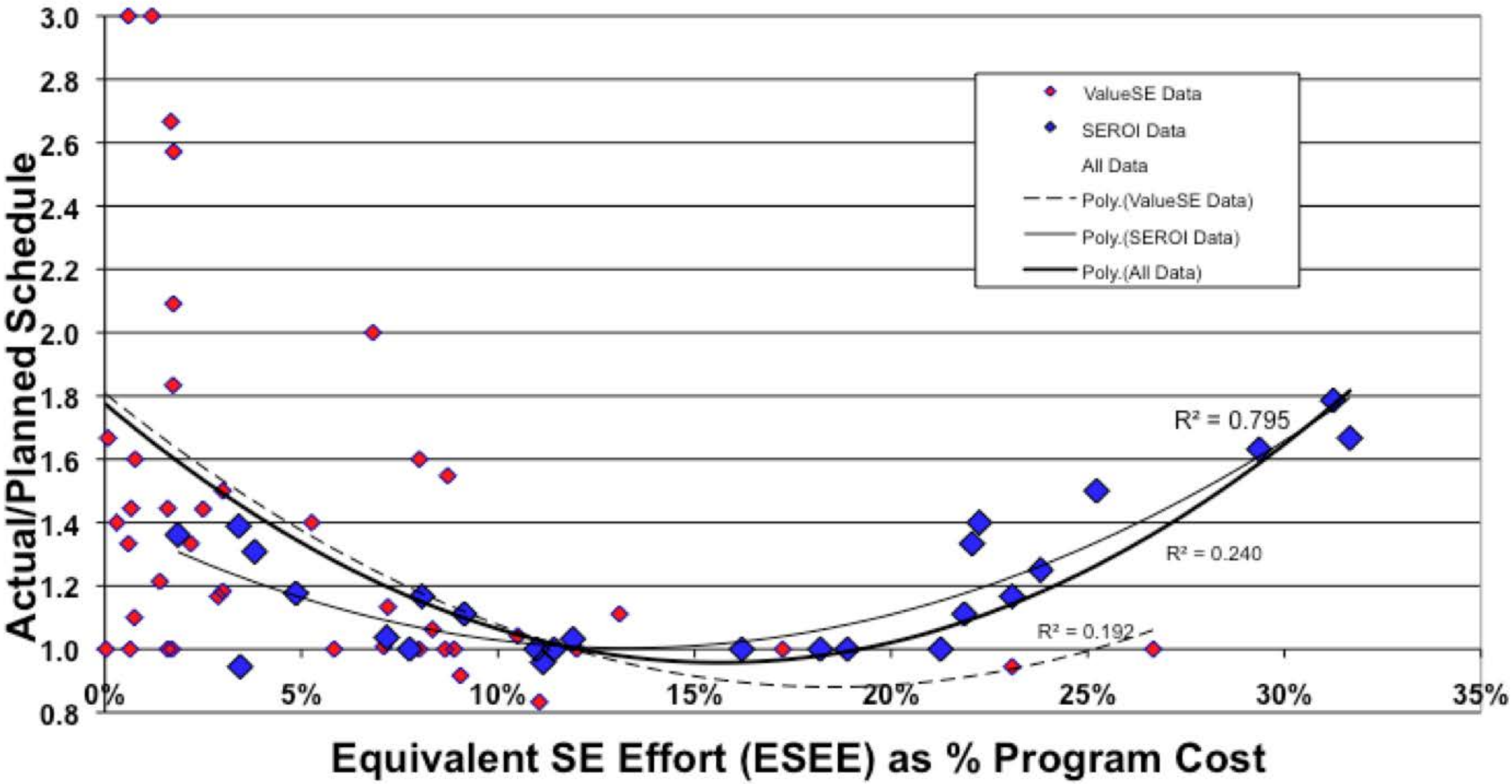
Schedule vs. SE Effort



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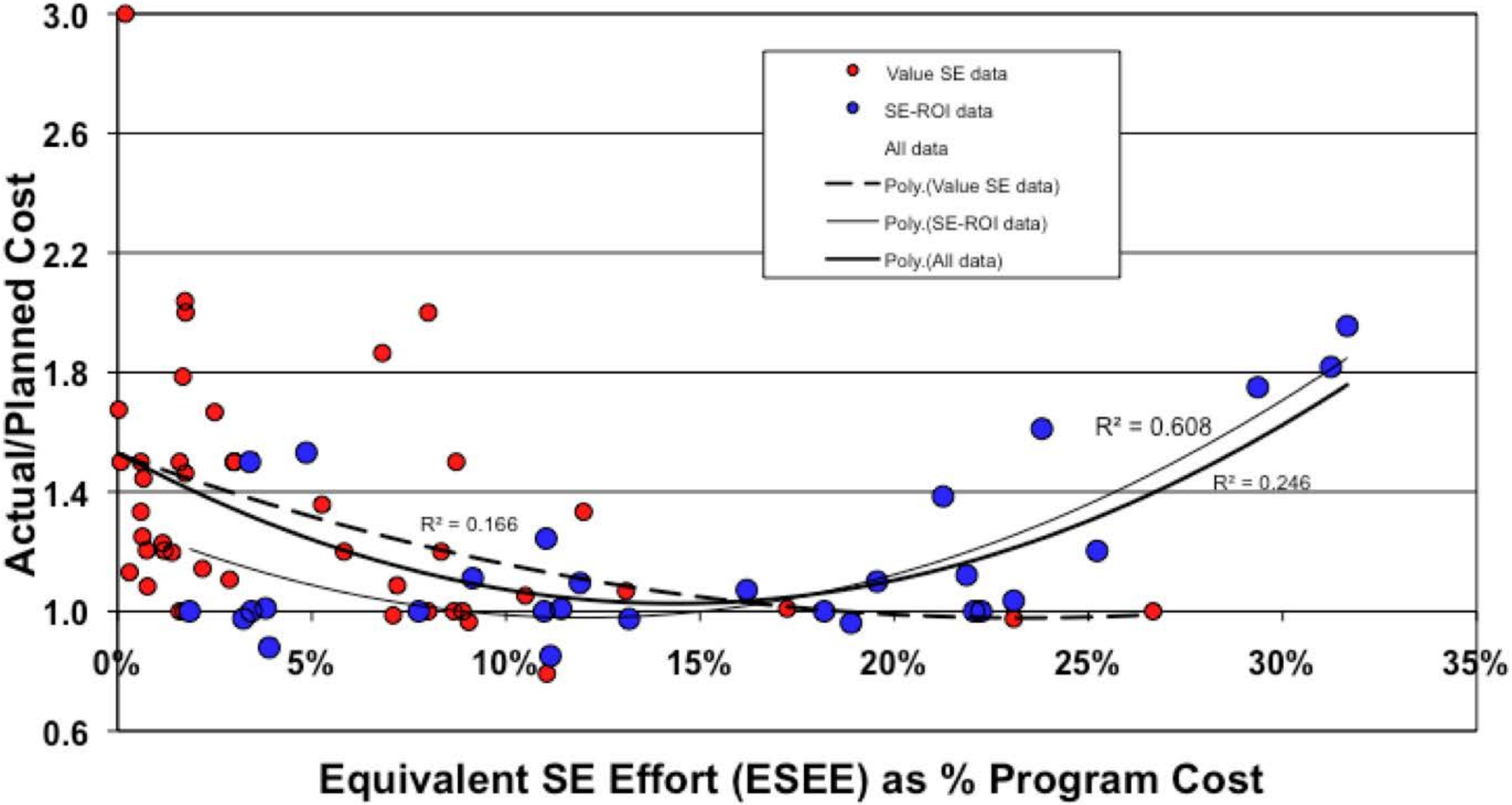
Cost vs. SE Effort



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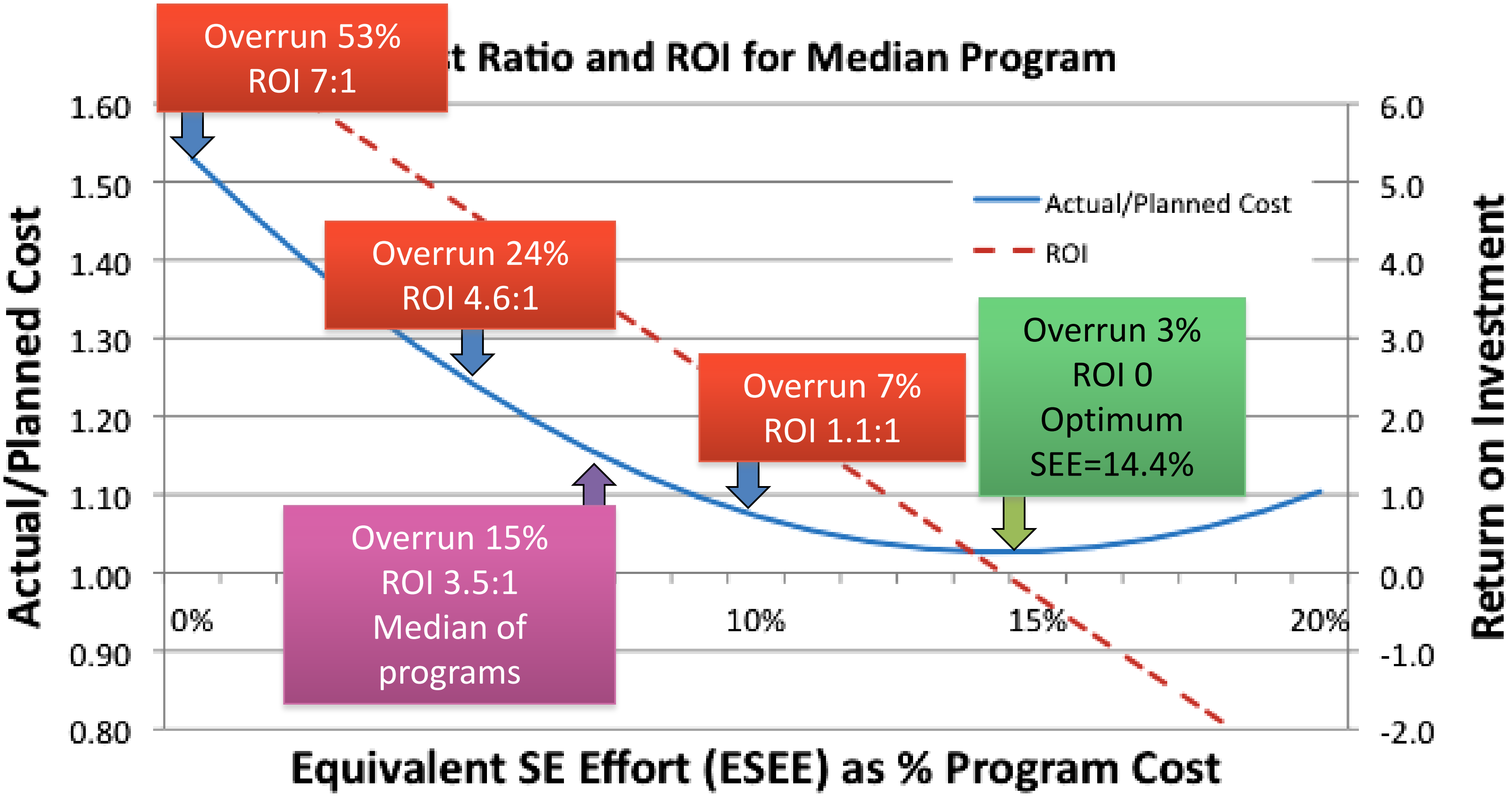
Return on Investment



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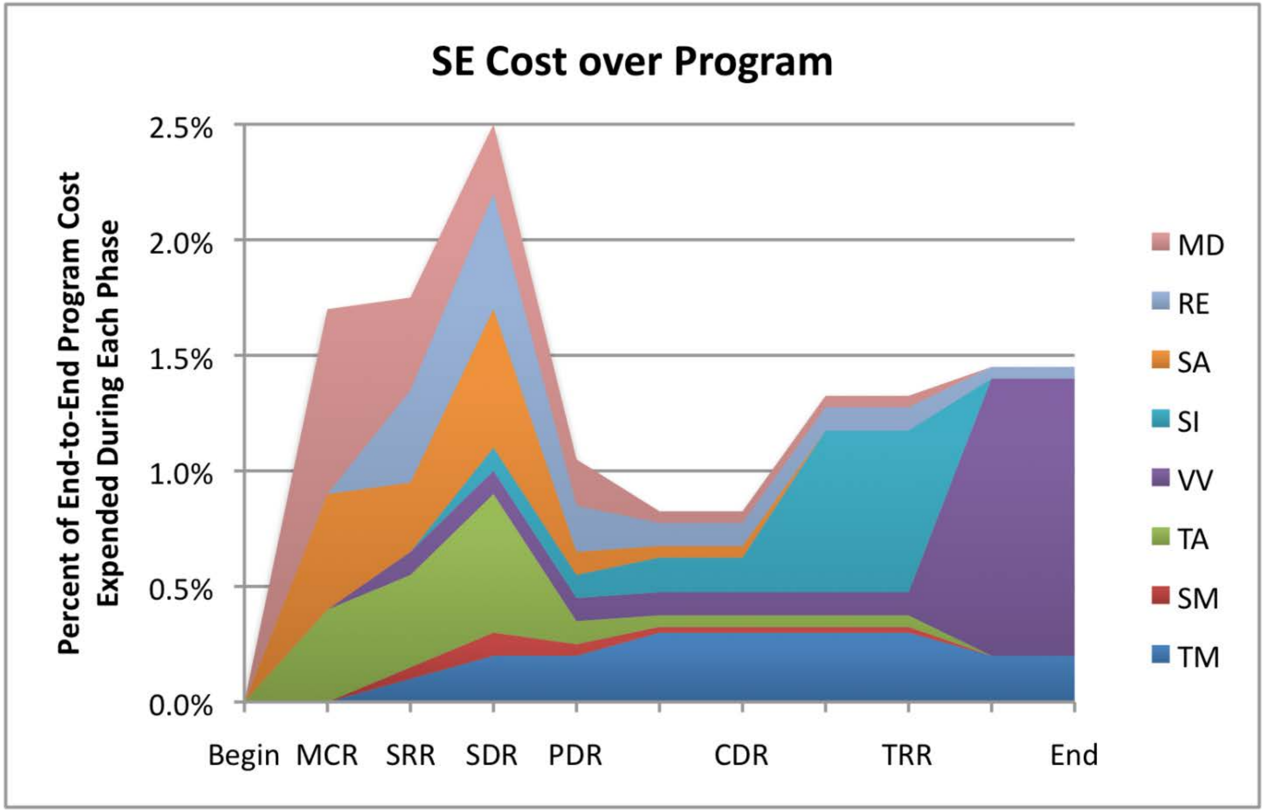
Breakout by SE Activities

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



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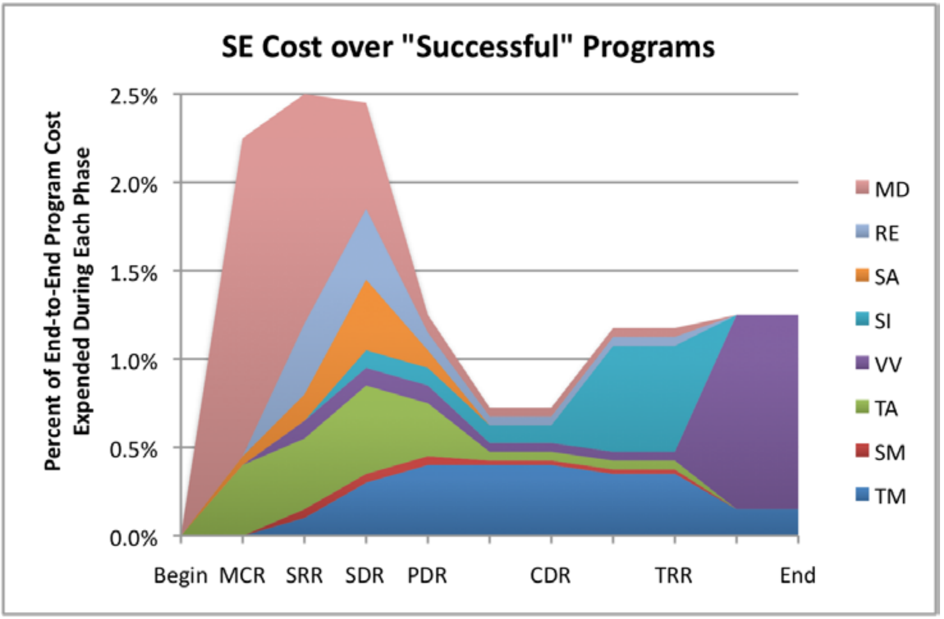
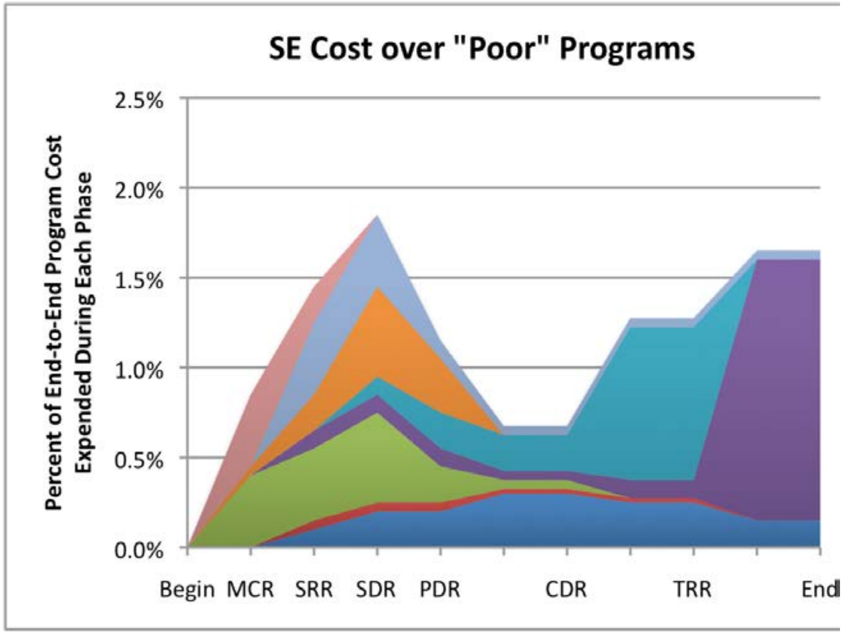
Breakout by Success





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

Poor *(overran cost)*
- More system integration
- More verification & validation
- Less Systems Engineering

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Systems Engineering Return on Investment

GAO-09-362T - Actions Needed to Overcome Long-standing Challenges with Weapon Systems Acquisition and Service Contract Management

• "costs … of major defense acquisition programs increased 26 percent and development costs increased by 40 percent from first estimates"

• "programs … failed to deliver capabilities when promised—often forcing warfighters to spend additional funds on maintaining legacy systems"

• "current programs experienced, on average, a 21-month delay in delivering initial capabilities to the warfighter"

Why?

"… managers rely heavily on assumptions about system requirements, technology, and design maturity, which are consistently too optimistic. <u>These gaps are largely the result of a lack of a disciplined systems engineering analysis prior to beginning system development</u> …

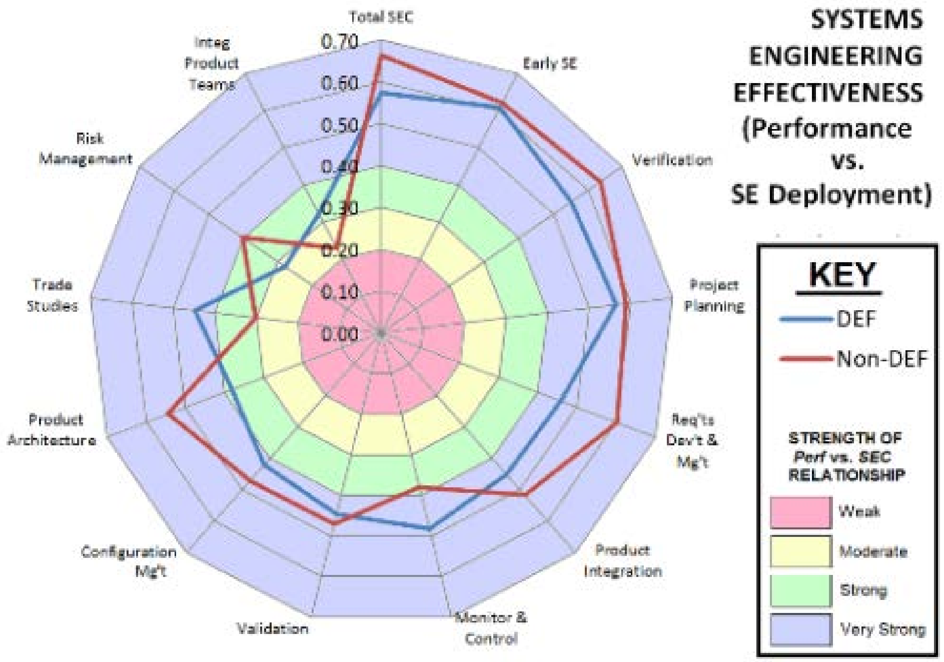
Systems Engineering Return on Investment

The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey CMU/SEI-2012-SR-009

This report summarizes the results of a survey that had the goal of quantifying the connection between the application of systems engineering (SE) best practices to projects and programs and the performance of those projects and programs. The survey population consisted of projects and programs executed by system developers reached through the National Defense Industrial Association Systems Engineering Division (NDIA-SED), the Institute of Electrical and Electronics Engineers Aerospace and Electronic Systems Society (IEEE-AESS), and the International Council on Systems Engineering (INCOSE). Analysis of survey responses revealed strong statistical relationships between project performance and several categories of specific SE best practices.

Projects that properly apply systems engineering best practices perform better than projects that do not.

Systems Engineering Return on Investment



The findings of our analysis are summarized as follows:

- For both defense domain projects and non-defense projects, projects with better SE deployment deliver, on average, better project performance.
- Non-defense projects deploy slightly less SE than defense projects
- Non-defense projects deliver slightly better project performance than defense projects, primarily due to better adherence to schedule.
- The strength of the relationships between SE deployment and project performance is stronger for non-defense projects than for defense projects.

Systems Engineering Return on Investment – Your Organization

The following list provides a description of the characteristics of good SE measures as well as questions to ask to determine if a measure has that particular characteristic.

Relevance - “Why do I want to collect this measure? Is there ambiguity in what it is trying to accomplish?” Only select measures that do not have numerous interpretations and that are pertinent to an end result you are trying to obtain.
Completeness - “Have I covered all the bases? Have I left out a key parameter that is needed to analyze my results? Is there a need to weight one parameter more than another?” Be sure you identify a balanced set of measures and that your emphasis does not become skewed.
Timeliness - “Did I find out what I needed to know in time to make a difference?” Be sure collection and analysis will provide the needed information in time to allow corrective action to be initiated.
Simplicity - “Can I collect and analyze the data easily and cost effectively? Can the users/managers understand what it means?” Keep it as simple and logical as possible. The measures should be easy to collect, analyze, and understand.

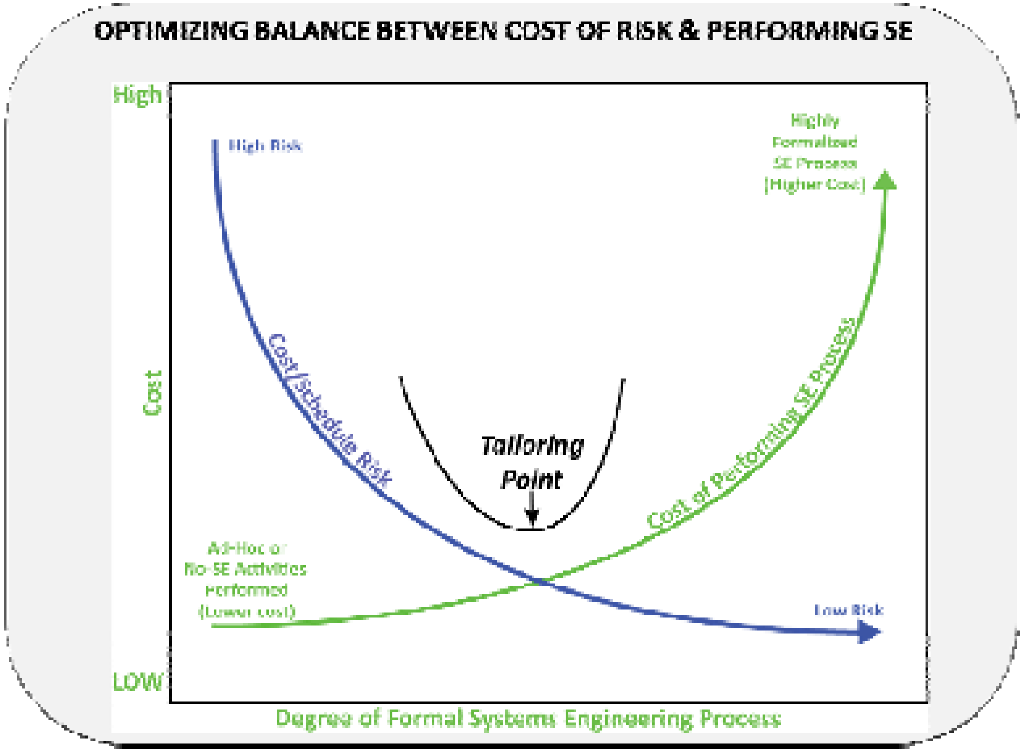
Systems Engineering Return on Investment – Your Organization

Cost Effectiveness - "Can I afford it? Can I not afford it? Does it provide more value than it costs?" Use data that is economical to collect. Use organizational or customer required data to address other project issues, where applicable. Leverage data collected for current management practices.

Repeatability - "Will the same conditions provide the same answer twice? Is the accuracy and precision adequate?" This is important for comparing measures across projects.

Accuracy - "Is my data really relevant to my purpose? Are my measures reliable? Am I measuring at the appropriate time?" Make sure that your measures are accurate and the resulting analysis accurately serves the intended purpose of the measure.

Systems Engineering Return on Investment – Your Organization



There is a cost associated with performing systems engineering process activities. A s the curve indicates, more formal SE activities result in higher costs. Concurrently, project risks are reduced as more formal SE activities are performed. There is an opt imized point where the degree of formal SE performed
crosses the risk curve.

The Shangri-La of Systems Engineering ROI

A popular and often-referenced paper is Sheard and Miller (2000) which describes the difficulties in attempting to define the ROI of SE. Through observation of the then-current state of measurement, they hypothesized that:

(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, and

(4) If you did use such numbers, no one would believe you anyway.

The Shangri-La of Systems Engineering ROI

The SE efforts on my program 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 program because …

… including SE costs in our bid will make it non-competitive.

… we don't have time for 'paralysis by analysis'. We need to get the design started.

… we don't have the budget or the people to support these efforts.

… SE doesn't produce deliverable outputs.

… our customer won't pay for them.

The Shangri-La of Systems Engineering ROI

Establishing knowledge of and adherence to SE best practices is essential from the start of a project.

Example: Configuration Management: SE had little understanding of the process & the level of implementation appropriate for Technology Development

Not implementing from inception made it difficult to instantiate later on within the IPT - **Resulted in rework during project close-out**

Inexperience is a big barrier to successful SE. Strong training base, weak in amount of experienced personnel

Systems Engineering is beneficial in regard to project cost, schedule and performance

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