A Practical Program of Research to Measure Systems Engineering Return on Investment (SE-ROI)

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Abstract. Past analysis has shown that there is a quantifiable correlation between the amount, types and quality of systems engineering efforts used during a program and the success of the program. For any given program, an amount, type and quality of systems engineering effort can be selected from the quantified correlations. The optimal nature of these selections, however, has not yet been explored. An ongoing project, Systems Engineering Return on Investment (SE-ROI), aims to quantify the correlations by gathering data on current and completed programs. This paper describes the practical program of research being used in the SE-ROI project and the current state of that development. The research program involves defining categorization sufficient to explore the correlations, implementing that categorization onto data sheets, gathering data from real programs through a personal interview process with the program leaders, and then performing statistical work to reveal the correlations. The project expects to achieve practical results in the form of (a) statistical correlation of SE methods with project success, to understand how much of each SE method is appropriate under what conditions, (b) leading indicators that can be used during a project to assess the project's expected future success and risks, and (c) identification of good SE practices that are appropriate to generate success under different conditions.[1]

Introduction

The challenges of developing and sustaining large complex engineering systems have grown significantly in the last decades. The practices of systems engineering promise to provide better systems in less time and cost with less risk, and this promise is widely accepted in industry. However, we lack specific evidence regarding the right amount of systems engineering to bring about the best results, as well as the correct timing for the application of system engineering and the identification of those SE tools that are most effective.

The project described in this paper has been developing for 13 years, through several different forms, largely matching the author's continuing interest in the value of systems engineering. The genesis of the project has been the companion observations that

- Systems engineering practices vary from project to project, even while core principles remain the same,
- The same practices seem to have highly variable results on different projects,

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- Published systems engineering materials usually ignore proof methods in favor of descriptive and prescriptive practices, and
- Well-respected systems engineers cannot seem to agree on best practices.

The intuitive understanding of the value of SE is shown in Figure 1. In traditional design, without consideration of SE concepts, the creation of a system product is focused on production, integration, and test. In a "system thinking" design, greater emphasis on the system design creates easier, more rapid integration and test. The overall result is a savings in both time and cost, with a higher quality system product. The primary impact of the systems engineering concepts is to reduce risk early, as shown in Figure 2. By reducing risk early, the problems during integration and test are prevented, thereby reducing cost and shortening schedule. The challenge in understanding the value of SE is to quantify these intuitive understandings.

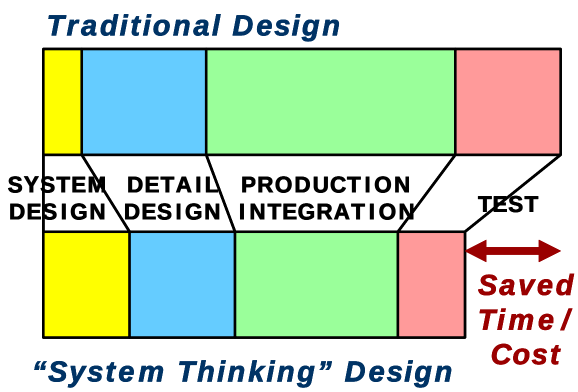

Figure 1. Intuitive Value of SE.

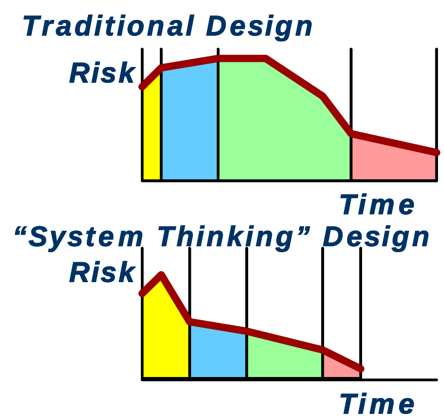

Figure 2. Risk Reduction by SE.

The Systems Engineering Return on Investment (SE-ROI) project gathers empirical information to understand how systems engineering methods relate to project success (defined in cost, schedule, and technical areas). In particular, the project expects to achieve three practical results:

1. ***Statistical correlation of SE methods with project success***, to understand how much of each SE method is appropriate under what conditions.
2. ***Leading indicators*** that can be used during a project to assess the project's expected future success and risks based on SE practices used.
3. ***Identification of good SE practices*** that are appropriate to generate success under different conditions.

There is little doubt that systems engineering has value. Systems engineers tend to be the most highly-paid individuals in most system development programs, with pay scales often exceeding those of the program managers. Systems engineers are given the responsibility of technical leadership, with associate authority for technical decisions. The practices used by systems engineers seem to provide significant early risk reductions that improve quality while reducing cost and schedule. The question is not whether systems engineering has value. The question is to quantify that value in a usable way.

Literature Research

Only a few studies have been reported that systematically quantify the value of systems engineering to programs. The author continues to research the literature for such information. [Honour 2004] reported seven directly applicable projects. Summarizing the findings of these projects in the context of systems engineering value:

- 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 2003]

The findings, however, are not conclusive. Each research project was undertaken for limited goals, and each project reflects the limitations of its goals and its available data. The types of development programs reported varied; data sets studied include NASA one-of-a-kind programs, commercial product development programs, manufacturing holding fixtures, and commercial software upgrades. While the results are useful, applying them to any specific system development program might not be appropriate.

The information so far is not directly usable. While it is useful to know that better or more systems engineering can reduce cost and schedule by significant amounts, the current state of knowledge does not indicate which practices are useful under what conditions. The data in the surveyed research projects has a wide degree of variance and suffers from limitations inherent in the scope of each research. When a program manager is faced with a decision to incorporate a new practice (e.g. more rigorous risk management), he/she has little information to indicate how much effort is appropriate and what return is to be expected from that effort.

Similar Current Projects

COSYSMO. The COSYSMO project [Valerdi 2003], managed by the University of Southern California, is gathering systems engineering data to create a constructive, parametric costing model for systems engineering. The project is aimed at providing a tool that can be used within industry, particularly for software-intensive programs. Because of the methods being used, COSYSMO is interested in matching the average systems engineering effort in the projects surveyed, rather than attempting to seek optimum cost levels for success. COSYSMO is not gathering success data.

NDIA Systems Engineering Effectiveness. The US National Defense Industries Association (NDIA) is pursuing a survey of systems engineering effectiveness through its participating companies. The project is managed for NDIA by the Carnegie-Mellon University (CMU) Software Engineering Institute (SEI). The approach is a survey approach, similar to [Honour 2004] but more detailed in nature. Work is still in progress.

SE-ROI Project Plan

The SE-ROI project implements a comprehensive and detailed gathering of information from real programs, both in-process and completed. The information to be gathered includes the time/expense used in performing specific systems engineering practices, the quality and type of those practices, and the apparent effects of those practices in terms of program quality, cost, schedule, and risk. For in-process programs, these interviews are repeated several times per year to evaluate the changes and effects as time progresses. For completed programs, the interviews are conducted once and correlated with data extracted from records. Gathering sufficient data to provide statistical significance requires access to about 20-30 programs over 2 or more years.

Standardization of the data requires using an interview process so that interviewers can perform a consistent interpretation of the native program data into common definitions. These interviewers need to be senior with extensive program management and systems engineering experience, unbiased, and capable of probing beyond the initial question to get at the true data. Interviewers include the principal investigator and others drawn from a project advisory group.

Standard forms for the interviews are important and must reflect the best perceived *a priori* organization of SE practices to be tested. Therefore, a first project step was to assemble a project advisory group to participate in creating this organization. Membership in the advisory group is still open as of this publication; see http://www.hcode.com/seroi for information. This advisory group serves several positive purposes for the project:

- Provide general acceptance of the data organization,
- Provide candidates to act as interviewers,
- Build public interest in the project and its expected results,
- Provide access to real programs in the group's parent organizations.

Incentives are offered to organizations to make their programs available for interview and analysis. The primary incentive offered is early access to the project results in the form of benchmark reports that compare the specific programs against the aggregate gathered data. Throughout the project, these reports are issued on a regular basis to keep the information flowing.

Data obtained from programs is obviously proprietary to the parent organizations, including key business parameters of technical success, cost, schedule and risk. Therefore, all interview data is maintained by the principal investigator in accordance with proprietary data agreements with the participating organizations. Raw interview data is not provided to the advisory group, because that group includes participants from various, possibly competing organizations.

Products. The project produces several types of products:

- A public website with summary information at http://www.hcode.com/seroi/.
- An organization of SE practices that is vetted by the advisory group, offered for publication as an interim technical paper.
- Interim analysis results, prepared as internal data and distributed to the advisory group.
- Benchmark reports, prepared as written reports to each participating organization. The reports will include specific data from the organization's interviewed programs, compared with aggregate data from the project as a whole.
- Final results in the form of a technical dissertation.

- Final results offered for publication as refereed, journal-level technical papers.

Expected Results. The expected results of the project are usable information for program managers, systems engineers, and organizational managers that provide indications:

- How much budget and time to plan for systems engineering practices?
- What specific benefits can be expected in terms of program quality, cost, schedule, and risk?
- Which systems engineering practices produce what effects?
- Under what program conditions is it appropriate to use more or less of each practice, and how much more or less?
- What interdependencies exist between SE practices?

SE-ROI Project Detailed Approach

The SE-ROI project is a three-year project with specific phases and products from each phase. This section describes the hypotheses, specific methods for data gathering, data protections, and technical analysis.

Hypotheses. Based on the background work of literature research, the primary hypotheses of the SE-ROI project are:

- There is a quantifiable correlation between the amount, types and quality of systems engineering efforts used during a program and the success of the program.
- For any given program, an optimum amount, type and quality of systems engineering effort can be predicted from the quantified correlations.

Several terms in these hypotheses require more definition. These include:

<u>Systems engineering effort</u> – The scope of systems engineering effort to be considered has been defined as a part of the project and is documented in [Honour 2006]. Based on an analysis of the existing standards and other work, the initially assumed scope includes the categories of mission/purpose definition, requirements engineering, system architecting, system implementation, technical analysis, technical management/leadership, scope management and verification/validation. These categories will be treated for data collection purposes as the independent variables of the research. .

<u>Amount</u> – Systems engineering effort can be quantified in terms of the man-hours of effort applied. As shown in SECOE project 01-03 [Honour 2004], however, this must also be qualified by a measure of the quality of the effort applied. For the exploration of secondary hypotheses, the amount of effort may be separated by the categories of effort.

<u>Type</u> –This project explores various types of processes and methods to seek correlations with the program success. The "type" of effort will be characterized by descriptive terms during program interviews. Aggregation of "types" will be performed during statistical analysis. For example, one type of <u>technical analysis</u> might be "the use of software-based Monte Carlo models to predict system performance."

<u>Quality</u> - The quality of systems engineering effort may be largely a matter of the processes and methods used on the program, and the applicability of those processes and methods to the specific program. However, the project also explores various subjective and objective measures of quality.

Success – The success of a program can be measured in several different ways. Based on the background work, the initially assumed measures include

a. Technical compliance with stakeholder needs, as described in [Browning 2005],
b. Cost compliance of the development program with its budgets,
c. Schedule compliance of the development program with its plans, and
d. Subjective customer/user/developer surveys.

Other success measures will be explored during interviews, including any program-unique success measures.

Optimum – The SE-ROI project seeks to discover the optimum relationships. The optimum is determined by correlation with program success. Due to the high degree of scatter expected in the data, this optimum is parameterized by various program characteristics.

The intent of the project, however, is to quantify the hypotheses in several lower-level dimensions that all support the primary hypotheses. This will result in a series of lower-level hypotheses that echo the primary hypotheses into detailed questions. The questions in the "Expected Results" subsection above demonstrate the results that are of interest to systems engineers and program managers. Typical lower-level hypotheses, therefore, include statements such as:

- There is a quantifiable correlation between the amount and quality of requirements engineering efforts used during a program and the success of the program. *(This hypothesis is repeated for each category of systems engineering activities.)*

- For any given program and quality level, an optimum amount of requirements engineering effort can be predicted from the quantified correlations. *(This hypothesis is also repeated for each category of systems engineering activities.)*

- Effective use of the systems engineering methodology or tool <NAME> correlates positively to the success of a development program. *(This hypothesis is repeated for any methodology that is repeated in the data sufficient times to provide statistical significance.)*

- Early presence of specific systems engineering indicator <NAME> correlates positively to the success of a development program. *(Again, this hypothesis is repeated for any known indicator that is repeated in the data sufficient times to provide statistical significance.)*

- Program defining characteristic <NAME> correlates positively with the successful use of systems engineering methodology or tool <NAME>. *(This hypothesis is repeated where data supports its exploration, as a variation on the success correlation of the methodology or tool.)*

The definition of technical correlations to be tested will bound these questions in real terms using the experience base of the advisory group. Such questions require more detailed approaches that necessitate design of the experiment in terms of structures.

Technical Structuring. A technical structuring phase of the project provides the technical concepts and data structures necessary to start data gathering. Work in this phase largely involves the members of a project advisory group comprised of interested representatives from many organizations. A similar approach was used on the COSYSMO project [Valerdi 2004a]. During this phase, the principal investigator acts as the primary worker while coordinating ideas and results with the advisory group. The work creates concepts and structures that are a consensus product of the advisory group. Specific goals for the phase are to create:

- Technical correlations to be tested by the project
- Data structures to obtain the necessary source data
- Access to real programs

Access to Real Programs. Programs may be either recently completed programs or ongoing programs. Programs are selected for accessibility to the applicable data and personnel. Selection bias is handled by careful definition of the bounds of all correlations. For completed programs, the intent is to gather final information that demonstrates the overall characterization, methods and success. For ongoing programs, the intent is to gather sufficient data to correlate the systems engineering practices with the short-term effect during development. Ideal programs are in various stages of development, progress through a variety of changes during the course of the research, and complete development during the research.

The number of programs from which data is gathered must be sufficient to support the statistical correlations desired in the technical structure. The greatest challenge of the SE-ROI project, as it was for prior projects including COSYSMO, is to obtain real data from sufficient programs. To this end, the principal investigator makes frequent contacts with industry and government individuals seeking access to the necessary program data.

Data Gathering. Supporting the primary hypotheses requires the following basic types of data:

- Project characterization data such as project size, project type, development phases, bounding parameters, risk levels.
- Project success data such as cost/schedule compliance and technical quality measures.
- Systems engineering data such as hours expended on systems engineering tasks, quality of those tasks, specific nature of the methods and tools used,

Such data is not usually stored directly in customer or contractor databases. Project databases store some equivalent data, but the data is organized in accordance with project, customer, or contractor structures. Interpretation of the data is needed to convert it into a common structure. For these reasons, the only effective method to obtain data is through an interview process with the key individuals.

The expected form of data gathering is to use one day in a sponsoring organization to obtain data from four projects. Each interview lasts 1-1/2 to 2 hours. Preferred participants are the program manager, chief systems engineer, program administrative clerk, and the project principal investigator. If available, a second SE-ROI project individual is desirable to help probe at the data. The interview time is structured around the technical structure and data sheets previously developed, with the intent to obtain a full set of data at one sitting. Data is obtained to the best level available. In some cases, data may be directly available from the program records. In other cases, data might be interpreted by the key individuals from the program records. In still other cases, data relies on the memory of the key individuals.

Data Protection. Data obtained from programs is obviously proprietary to the parent organizations, including key business parameters of technical success, cost, schedule and risk. Therefore, all interview data must be maintained in such a way as to positively protect the data from either inadvertent or malicious disclosure.

Prior to any data gathering at an organization, the project executes a proprietary data agreement with the organization. The form of the agreement may be as required by the organization, or may be offered by the SE-ROI project. Essential terms of the agreement are to allow sufficient access to program data, and to ensure that the data is not released in any way that provides attribution of the data to the source organization.

Actual practice of the SE-ROI project uses the following protections to secure the data:

- Data sheets are identified only with a blind randomized code. No data is recorded that identifies the organization or the people involved.
- The key that links the blind codes to the actual organizations and projects is maintained in a single hard copy record. Only the principal investigator has access to the key.
- Raw interview data, even though it is tagged only with the blind code, is limited to the principal investigator and any assistants performing data analysis. This data is specifically not provided to the project advisory group, because that group includes participants from various, possibly competing organizations.
- Aggregated data resulting from fewer than five source interviews is also limited to the principal investigator, any assistants performing data analysis, and the source organization. This same practice is applied to aggregated data from fewer than three source organizations. This practice is to prevent inference of organizational data from the aggregated data.
- Aggregated data from one source organization may be included in the benchmark reports provided to that source organization.
- Other practices may also be instituted as deemed necessary by the principal investigator, the guidance bodies, or the source organizations.

Technical Analysis. Because the purpose of the project is to seek statistical correlations to support the hypotheses, the technical analysis methods rely on statistical methods. Each lower-level hypothesis is negated into a null hypothesis. For each null hypothesis, data correlations are sought to disprove. By logical inference, the disapproval of the null hypotheses supports the original hypothesis to a calculated degree of confidence.

In each case, the correlations are further complicated by the varying methods and quality of systems engineering that are expected at source organizations. Correlations will also be sought by examination of the data structure along with the anecdotal information on methods and quality. It is expected that such a search will reveal some methods that appear to lead to better program success than others, but the search may also reveal methods that provide no correlation with program success.

Example of Results. The result of technical analysis is a series of mathematical correlations between pairs of data items, each correlation dependent on the condition of other data items. Each correlation is supported by a significance level and degree of confidence. For example, one such correlation may define the relationship between “percent of project work effort used to perform risk management” and “technical compliance with objectives.” In this case, it is likely that the correlation may be further dependent on data items such as “quality of the risk management effort,” “program overall cost (size),” and/or “technology readiness level at program start.” In a rigorous statistical analysis, these correlations can be proven mathematically from the data.

In an informal result, however, the correlations can be shown graphically for use as guidance in optimal selection. Based on the graphical representation, managers may decide on a level of funding for this particular activity (risk management).

Conclusions

This paper presents a summary of an ongoing project to quantify the Return on Investment of Systems Engineering through empirical means. The challenges in such quantification have always been:

- Comparable variations in complex programs (i.e. scientific control of the experiment)
- Access to real data from real projects
- Rigor in statistical methods

The project methods described in this paper address each of these challenges. By collecting data from many programs, the variations in the programs provide the requisite variety that allows a design-of-experiments approach to empirical correlations. By the use of a project advisory group and benchmarking reports, data from many real projects can be gathered. By appropriate and rigorous statistical methods, the correlations can be properly stated to provide an empirical basis of information that has never before existed.

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Biography

Eric Honour was the 1997 INCOSE President. He has a BSSE from the US Naval Academy and MSEE from the US Naval Postgraduate School, with 37 years of systems experience. He is currently a doctoral candidate at the UniSA SEEC. He was a naval officer for nine years, using electronic systems in P-3 anti-submarine warfare aircraft. He has been a systems engineer, engineering manager, and program manager with Harris, E-Systems, and Link. He has taught engineering at USNA, at community colleges, and in continuing education courses. He was the founding President of the Space Coast Chapter of INCOSE, the founding chair of the INCOSE Technical Board, and a past director of the Systems Engineering Center of Excellence. He was selected in 2000 for Who’s Who in Science and Technology and in 2004 as an INCOSE Founder. Mr. Honour provides technical management support and systems engineering training as President of Honourcode, Inc., while continuing research into the quantification of systems engineering.