Gathering Data to Measure Systems Engineering Return on Investment (SE-ROI)

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Abstract. Research has shown that there is a quantifiable correlation between the amount, types and quality of systems engineering efforts used during a programme and the success of the programme. 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 programmes. This paper describes the practical programme of research being used in the SE-ROI project and the data gathering that is starting. The research programme involves defining categorization sufficient to explore the correlations, implementing that categorization onto data sheets, gathering data from real programmes through a personal interview process with the programme leaders, and then performing statistical work to reveal the correlations. This paper summarizes the data sheets being used. The project expects to achieve practical results in the form of (a) statistical correlation of SE methods with programme success, to understand how much of each SE method is appropriate under what conditions, (b) leading indicators that can be used during a programme to assess the programme'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 some industries. 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 Systems Engineering Return on Investment (SE-ROI) project [Honour 2006b] gathers empirical information to understand how systems engineering methods relate to programme success. In particular, the project expects to achieve three practical results:

1. ***Statistical correlation of SE methods with programme success***, to understand how much of each SE method is appropriate under what conditions.
2. ***Leading indicators*** that can be used during a programme to assess the programme'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.

SE-ROI PROJECT PLAN

The SE-ROI project implements a comprehensive and detailed gathering of

[1] This paper was published in the proceedings of the Systems Engineering/Test and Evaluation (SETE) conference, Melbourne, VIC, 2006.

information from real programmes, 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 programme quality, cost, schedule, and risk. For in-process programmes, these interviews are repeated several times per year to evaluate the changes and effects as time progresses. For completed programmes, 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 programmes 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 programme data into common definitions. These interviewers need to be senior with extensive programme 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 programmes in the group's parent organizations.

Incentives are offered to organizations to make their programmes 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 organization specific programmes against the aggregate gathered data. Throughout the project, these reports are issued on a regular basis to keep the information flowing.

Data obtained from programmes is obviously proprietary to the parent organizations, including key business parameters of technical success, cost, schedule and risk and individual business thresholds for acceptable measures of these dimensions when planning and reviewing programmes. 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. [Honour 2006a]
- 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 programmes, 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 programme managers, systems engineers, and organizational managers that indicate:

- How much budget and time to plan for systems engineering practices?
- What specific benefits can be expected in terms of programme quality, cost, schedule, and risk?
- Which systems engineering practices produce what effects?

- Under what programme 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 DATA GATHERING

The SE-ROI project is a three-year project with specific phases and products from each phase. The project is still in its first year, although useful data has already been reported.

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 programme and the success of the programme.
- For any given programme, 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:

Systems engineering effort – The scope of systems engineering effort to be considered has been defined as a part of the project and is documented in [Honour 2006a]. Based on an analysis of the existing standards and other work, the initially assumed scope includes the eight 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.

Amount – 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.

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

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

Success – The success of a programme 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 programme with its budgets,

c. Schedule compliance of the development programme with its plans, and

d. Subjective customer/user/developer surveys.

Other success measures will be explored during interviews, including any programme-unique success measures and measures related to strategic positioning of the organization performing the programme

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

Structure of Systems Engineering. An initial research goal in SE-ROI was to define a useful categorization of systems engineering activities. This categorization needed to be widely accepted. Therefore, a review of the various systems engineering standards was undertaken and reported in [Honour 2006a]. This review revealed eight categories that were largely in common across the five systems engineering standards reviewed:

- Mission/Purpose Definition. Includes (a) describing the mission and (b) quantifying the stakeholder preferences. Usually done in the language of the system users rather than in technical language, often performed by marketing groups or a contracting agency before involving systems developers.

- Requirements Engineering. Creation and management of requirements, formal technical statements that define the capabilities, characteristics, or quality factors of a system. May include efforts to define, analyse, validate, and manage the requirements.
- System Architecting. Synthesizing a design for the system in terms of its component elements and their relationships. Diagrams depict the high-level concept of the system in its environment, the components of the system, and the relation of the components to each other and to the environment. Process usually involves generation and evaluation of alternatives, then defining the components by the use of allocated requirements.
- System Implementation. Systems engineering effort to support creation of a first functioning or prototype system that meets the defined mission or purpose. Specific system efforts include system integration and transition to use.
- Technical Analysis. Multi-disciplinary analysis focused on system emergent properties, usually used either to predict system performance or to support decision trade-offs. Includes functional analysis, predictive analysis, and trade-off analysis, except when inseparable from requirements engineering or system architecting. Also includes performance analysis, timing analysis, capacity analysis, quality analysis, trending, sensitivity, failure modes and effects analysis, technical performance measurement, and other similar technical evaluations of the system configuration and components.
- Technical Management/Leadership. Efforts to guide and coordinate the technical personnel toward the appropriate completion of technical goals. These tasks encompass elements of programme planning, technical progress assessment, technical control, team leadership, inter-discipline coordination, providing common language and goals, risk management, configuration management (when performed as part of leadership), and interface management.
- Scope Management. Technical definition and management of acquisition and supply issues. Defining technical contractual relationships both upward (development contract or marketing definition) and downward (subsystem or component definition/control).
- Verification and Validation. Verification is the comparison of the system (or developmental artefacts) with its requirements through the use of objective evidence. Validation is the comparison of the completed system (or artefacts) with the intended mission.

Data Gathering. The expected form of data gathering is to use one day in a sponsoring organization to obtain data from four programmes. Each interview lasts 1-1/2 to 2 hours. Preferred participants are the programme manager, chief systems engineer, programme administrative clerk, and the SE-ROI 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 data sheets previously developed. Data is obtained to the best level available. In some cases, data may be directly available from the programme records. In other cases, data might be interpreted by the key individuals from the programme records. In still other cases, data relies on the memory of the key individuals.

Supporting the primary hypotheses requires the following three basic types of data.

Programme Characterization – The statistical correlations to be explored will be parameterized by various programme characteristics. The data sheets provide for characterization by the parameters shown in Table 1 and the subjective measures shown in Table 2.

Programme Success – The dependent variable assumed in the project hypotheses is programme success, which can be measured in several different ways. The data sheet of Table 3 provides for measurement of success in financial, schedule, labor, and technical terms, as well as stakeholder success measures. There is also room to record any additional success measures used at the organization.

Table 1. Programme Characterization Data

PROGRAMME ENVIRONMENT – Check one appropriate box in each group.

PROGRAMME FUNDING METHOD	**LEVEL OF SYSTEM DEFINITION AT START**
❑ Contracted development* – customer creates contractual relationship with the developer ❑ Amortized development* – developer creates system product for a defined market segment ❑ Purchase/integration* - using organization purchases and integrates components for own use.	❑ Poorly-defined user problem ❑ User problem well defined. ❑ Meta-system architecture diagrammed ❑ System mission/operations defined ❑ Performance-based requirements documented ❑ Complete system technical requirements documented. ❑ System architecture diagrams completed to next-level components ❑ Technical requirements allocated to next-level components

LIFE-CYCLE IDENTIFICATION – Check one appropriate box in each group.

ENTERPRISE LIFE-CYCLE PHASE	**ENGINEERING LIFE-CYCLE PHASE AT INTERVIEW**
❑ Concept ❑ Development ❑ Production ❑ Utilization ❑ Support ❑ Retirement	❑ Operational definition ❑ Requirements definition ❑ System architecting ❑ Preliminary design ❑ Detailed design ❑ System integration ❑ Test & evaluation ❑ Completed

GRADED QUANTITIES – Enter three specific numeric values for each.

	EASY	**NOMINAL**	**DIFFICULT**
Number of system requirements			
Number of system interfaces (external)			
Number of algorithms			
Number of operational scenarios			

OTHER QUANTITIES – Enter a specific numeric value for each.

	NUMBER		**NUMBER**
Number of unique components* in the system design		Number of developing organizations*	
Number of unique components* designed as part of the programme		Number of customer agencies* actively involved in the programme	
Number of components* integrated per system (multiple instances count)		System production quantity under this programme	
Number of documented trade studies* at the system level		Number of installation locations	
Number of formal tests* at the system level		CMMI level of parent organization (prime developer only)	
Number of formal test locations* at the system			

*See definitions

Table 2. Programme Subjective Parameters

SUBJECTIVE PARAMETERS - Evaluate each parameter on the scale given

Parameter	VL	L	N	H	VH	EH
Mission/purpose understanding	❑	❑	❑	❑	❑	
Requirements understanding	❑	❑	❑	❑	❑	
Requirements volatility (changes to requirements)	❑	❑	❑	❑	❑	
Requirements growth (additions to requirements)	❑	❑	❑	❑	❑	
Architecture understanding	❑	❑	❑	❑	❑	
Overall system complexity	❑	❑	❑	❑	❑	
Level of service requirements (environmental, safety, security, reliability, maintainability, etc.)	❑	❑	❑	❑	❑	
Migration complexity			❑	❑	❑	❑
Technology risk	❑	❑	❑	❑	❑	
Documentation	❑	❑	❑	❑	❑	
Number and diversity of installations/platforms			❑	❑	❑	❑
Number of recursive levels in the design	❑	❑	❑	❑	❑	
Stakeholder team cohesion	❑	❑	❑	❑	❑	
Personnel/team capability	❑	❑	❑	❑	❑	
Personnel experience/continuity	❑	❑	❑	❑	❑	
Lead system engineer experience level	❑	❑	❑	❑	❑	
Process capability	❑	❑	❑	❑	❑	❑
Multisite coordination	❑	❑	❑	❑	❑	
Tool support	❑	❑	❑	❑	❑	
Overall quality of systems engineering	❑	❑	❑	❑	❑	

Scale: VL=Very Low; L=Low; N=Nominal; H=High; VH=Very High; EH=Extremely High

Table 3. Programme Success Data

PROGRAMME SUCCESS MEASURES (COST/SCHEDULE/TECHNICAL)

Original planned cost ($ Total)	Original planned schedule (Months)	Original planned labor (Person-hrs)
Current projected cost ($ Total)	Current projected schedule (Months)	Current projected labor (Person-hrs)
Current cost expended ($ at time of interview)	Current schedule expended (Months after programme start)	Current schedule labor (Person-hrs)

Key Performance Parameter* (List the top 4 to 8)	Weight %	Threshold Value*	Goal Value*	Projected Value

STAKEHOLDER SUCCESS MEASURES

Amortized development – developer creates system product for a defined market segment	
Projected return on investment (%)	Projected period of return (Months after programme start)
Contracted development – customer creates contractual relationship with the developer	
Projected contract profit (% of cost)	

Table 4. Systems Engineering Effort Data (One of Eight Categories)

2. REQUIREMENTS ENGINEERING

PROJECTED TOTAL EFFORT (PERSON-HR)	**PROJECTED TOTAL COSTS ($)**
METHODS & TOOLS – REQUIREMENTS ENGINEERING Describe the methods and tools used to perform requirements engineering and subjective evaluations of the quality and effectiveness of the methods.	
METRICS – REQUIREMENTS ENGINEERING List any metrics used by the programme to evaluate the system requirements. Include the current value of each metric	

Systems Engineering Effort – The independent variable assumed in the project hypotheses is systems engineering effort. Given the categorization of [Honour 2006a], systems engineering effort is measured against each of the eight task categories using the data sheet of Table 3 (one for each category; only category 2 is shown).

Data Protection. Data obtained from programmes 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 programme 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 programmes 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. This provision precludes parent organization deduction through aggregation of data elements.
- 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.

CONCLUSIONS

This paper presents the data gathering efforts of an ongoing project to quantify the Return on Investment of Systems Engineering through empirical means. Work continues to obtain the data through interviews with real programmes.

The data gathering methods described in this paper address each of the challenges. By collecting data from many programmes, the variations in the programmes 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 programmes 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.

The expected results from the SE-ROI project are to provide an understanding of the relationship between systems engineering efforts and the success of a programme.

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REFERENCES

Browning, T. and Honour, E., “Measuring the Life Cycle Value of a System,” *INCOSE International Symposium*, Rochester, NY, 2005.

Honour, E.C., “Understanding the Value of Systems Engineering,” *Proceedings of the*

INCOSE International Symposium, Toulouse, France, 2004.

Honour, E.C. and Valerdi, R, "Advancing an Ontology for Systems Engineering to Allow Consistent Measurement," *Conference on Systems Engineering Research*, University of Southern California, Los Angeles, CA 2006

Honour, E.C., "A Practical Program of Research to Measure Systems Engineering Return on Investment (SE-ROI)," *INCOSE International Symposium*, Orlando, FL 2006

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.