Demographics in Measuring Systems Engineering Return on Investment (SE-ROI)

Eric C. Honour
University of South Australia
Mawson Lakes, SA
Honourcode, Inc.
+1 (850) 479-1985 (Pensacola, FL)
eric.honour@postgrads.unisa.edu.au

Abstract. Research work continues into Systems Engineering Return on Investment (SE-ROI) following prior work on Value of Systems Engineering and Systems Engineering Effectiveness. In the current work, 1.5-hour interviews are being held with the leaders of completed system development programs to obtain extensive data on systems engineering activities, program success measures, and possible correlative parameters. The resulting information is being examined statistical to determine empirical knowledge about the return on investment of systems engineering activities. As of this writing, interesting results in the demographics have been observed based on 30 program interviews. This paper provides information showing (a) source information on the interviewed programs, (b) observed quantitative breakdown of systems engineering effort into eight activities, (c) histogram spreads of the observed characteristics of the source programs, and (d) histogram spreads of the observed correlative parameters. The paper also provides initial indications of the differences between successful and unsuccessful programs.

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 2006a) gathers empirical information to understand how systems engineering methods relate to program 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.

[1] This paper was published in the proceedings of the INCOSE International Symposium, Singapore 2009.

The SE-ROI project continues the major work reported in prior publications. In the Value of Systems Engineering work (Honour 2004), the author quantitatively demonstrated the relationship between systems engineering and program success using anonymous surveys. The graphic results reported in that work have been widely used internationally, indicating that systems engineering effort is optimized at a level of 10-15% of the total program cost. At this level, both cost and schedule overrun appear to be minimized. In the Systems Engineering Effectiveness report (Elm et al. 2007), more extensive surveys provided further detail into the relationships between specific systems engineering activities and program success. The results indicated moderately strong correlation with success for the following capabilities (in order of correlation strength): product architecture, trade studies, technical solution, integrated product teams, and others.

Other prior works also provide anecdotal quantifications based on limited source data or limited conditions. There is a summary of prior works in (Honour 2004).

SE-ROI Project Plan

Interview Method. The SE-ROI project implements a comprehensive and detailed gathering of information from real programs. The information gathered includes the time/expense used in performing specific systems engineering practices; the quality and type of those practices; correlative parameters such as team understanding, team capability, and program difficulty; and the success of the programs in terms of technical, cost and schedule measures. Gathering sufficient data to provide statistical significance requires access to about 20-30 programs. This level has now been accomplished, but interviews continue to provide sufficient data points to allow more detailed structuring.

Standardization of the data requires using a structured interview process so that interviewers can perform a consistent interpretation of the native program data into common definitions. These interviewers are senior individuals 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 reflect the best perceived *a priori* organization of SE practices to be tested. An early step in the research, therefore, was to define and obtain review on an ontology sufficient to provide useful and widely-accepted categorization of systems engineering activities. The ontology and resulting categorization was reported in (Honour/Valerdi 2006). Following the development of this categorization, the project developed and tested interview data sheets to obtain the necessary data (Honour 2006b). The interview data sheets were further reviewed through conference publication and detailed peer/supervisory review.

Program Access. The research is based on real programs, for which data can be both proprietary and difficult to obtain. Therefore, an early project step was to assemble a project advisory group to participate in defining the project. 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 organization 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 and individual business thresholds for acceptable measures of these dimensions when planning and reviewing programs. 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/.
- Benchmark reports, prepared as written reports to each participating organization. The reports include specific data from the organization's interviewed programs, compared with aggregate data from the project as a whole.
- Interim analysis results, prepared as internal data and distributed to the participating organizations on a regular basis.
- Final results in the form of a technical dissertation submitted to the University of South Australia in qualification for a Doctor of Philosophy degree.
- 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 indicate:

- 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?

Basic Demographics

Sources of Data. SE-ROI interviews started in 2007 and continue through this publication. The data on which this report is based comes from two different data sets, obtained using different methods.

- "Value of Systems Engineering" data includes 44 program data points obtained during 2001-2004 as a part of the prior project (Honour 2004). This data was obtained through voluntary, anonymous surveys using a simple data sheet.

- "SE-ROI" data includes 30 program data points obtained during 2007-2008 as a part of the SE-ROI project. This data was obtained using interviews guided by the interview data sheet designed for SE-ROI.

Table 1 displays the primary demographics of the data so far, including funding methods, cost and schedule compliance, and systems engineering content.

Table 1: Basic Demographic Data

Characteristic	ValueSE Data Set	SE-ROI Data Set
Number of organizations	Unknown	12
Number of data points	44	30
Funding method	Unknown	24 contracted, 6 amortized
Program total cost	\$1.1M - \$5.6B Median \$42.5M	\$600K - \$1.8B Median \$12.0M
Cost compliance	(0.8):1 – (3.0):1 Median (1.2):1	(0.6):1 – (10):1[2] Median (1.0):1
Development schedule	2.8 mo. – 144 mo. Median 43 mo.	2 mo. – 120 mo. Median 32 mo.
Schedule compliance	(0.8):1 – (4.0):1 Median (1.2):1	(0.3):1 – (2.5):1 Median (1.0):1
Percent of program used in systems engineering effort, by cost	0.1% - 27% Median 5.8%	4% - 80%[3] Median 14.8%
Subjective assessment of systems engineering quality (scale of 1 poor to 10 world class)	Values of 1 to 10 Median 5	Values of 1 to 9 Median 7

Validation of the Combined Data. Using two different data sets raises the question of the compatibility of those data sets. At the highest level, compatibility has been checked by comparing the primary results of the two data sets: correlation of systems engineering effort with program cost and schedule compliance. The report in (Honour 2004) provided graphics showing this correlation that have been widely used internationally to demonstrate the value of systems engineering. Figures 1 and 2 update those prior graphics with the inclusion of the SE-ROI data. In each figure, the small red diamonds represent the prior "Value of Systems Engineering" data, while the larger blue circles represent the SE-ROI interview-based data. It can be seen that the interview-based SE-ROI data fits well within the prior data, leading to a tentative conclusion that the two data sets are compatible. The graphs also show 2nd order polynomial fit trend lines to the SE-ROI data and to all data; it should be specifically noted that the trend lines are compatible.

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[2] (Table 1, "Cost compliance") This amortized program had a highly excessive overrun in cost, likely due to poor estimation of effort. The next largest cost overrun is 3:1.

[3] (Table 1, "Percent … systems engineering effort") There were four outlier points with very large SE content at 80%, 51%, 46% and 31%. All other programs have SE content at less than 25%. All four projects were systems whose component design was relatively simple, so that the systems engineering activities extended well into what would normally be component architecting and design.

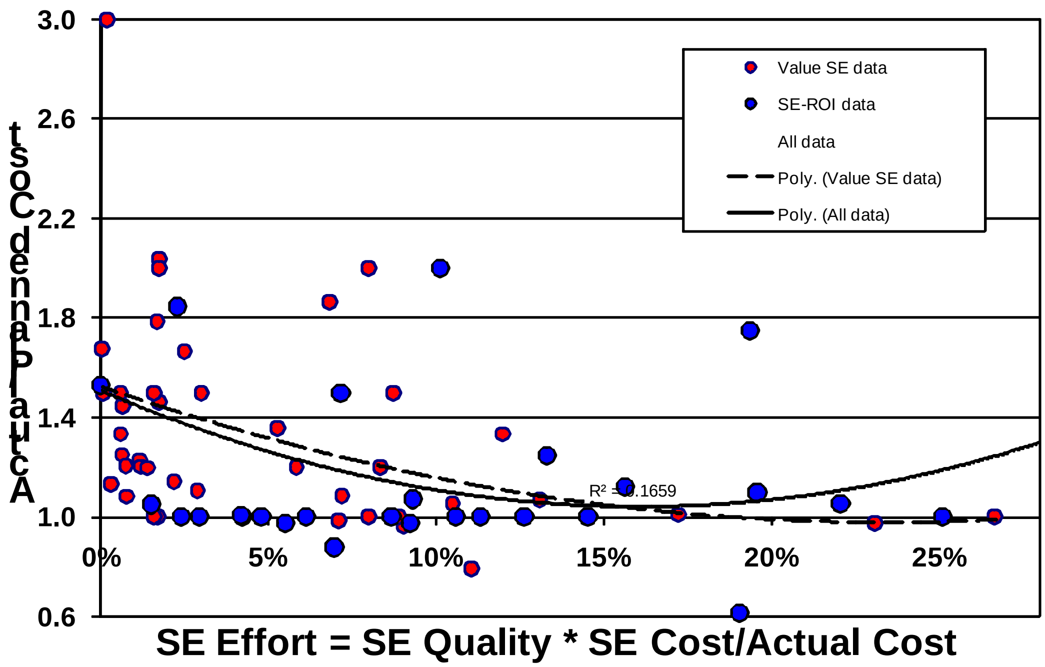

Figure 1: Cost Overrun vs. Systems Engineering Effort

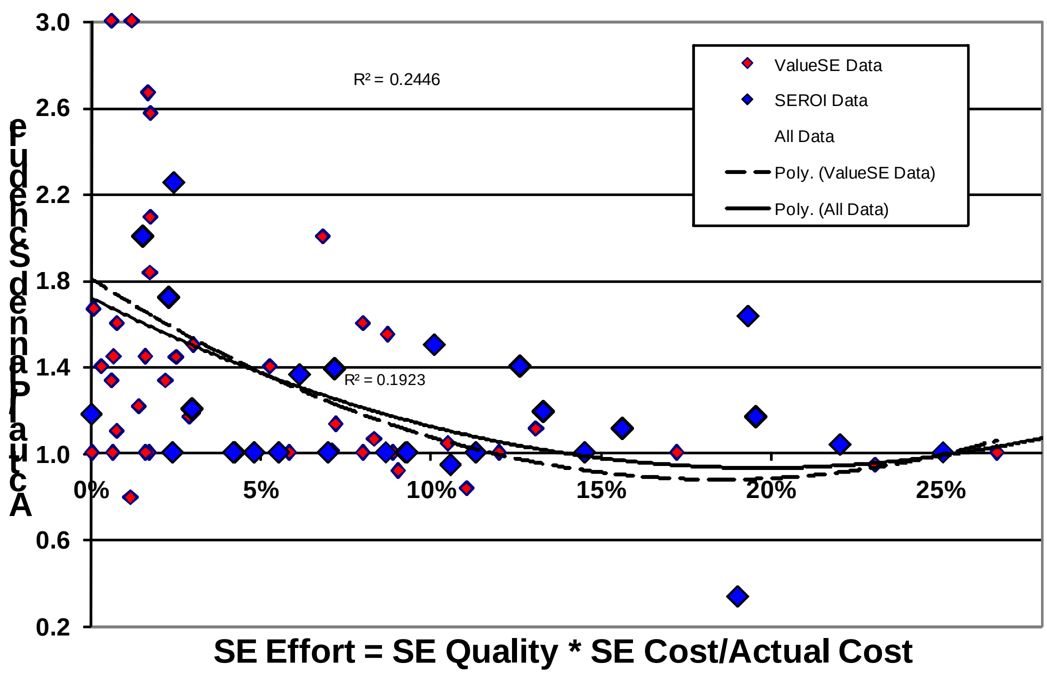

Figure 2: Schedule Overrun vs. Systems Engineering Effort

Source Program Size Characteristics. Within the SE-ROI data, the interviews include a series of questions on the "size" characteristics of the source programs. Figure 3 provides histograms of several key parameters, demonstrating the variety of programs interviewed. It can be seen that programs varied significantly in start point and in numbers of requirements, interfaces, algorithms, and operational scenarios. Most programs were in the "Development" life-cycle stage, but regardless of life-cycle stage, all programs were a development of an identifiable new capability.

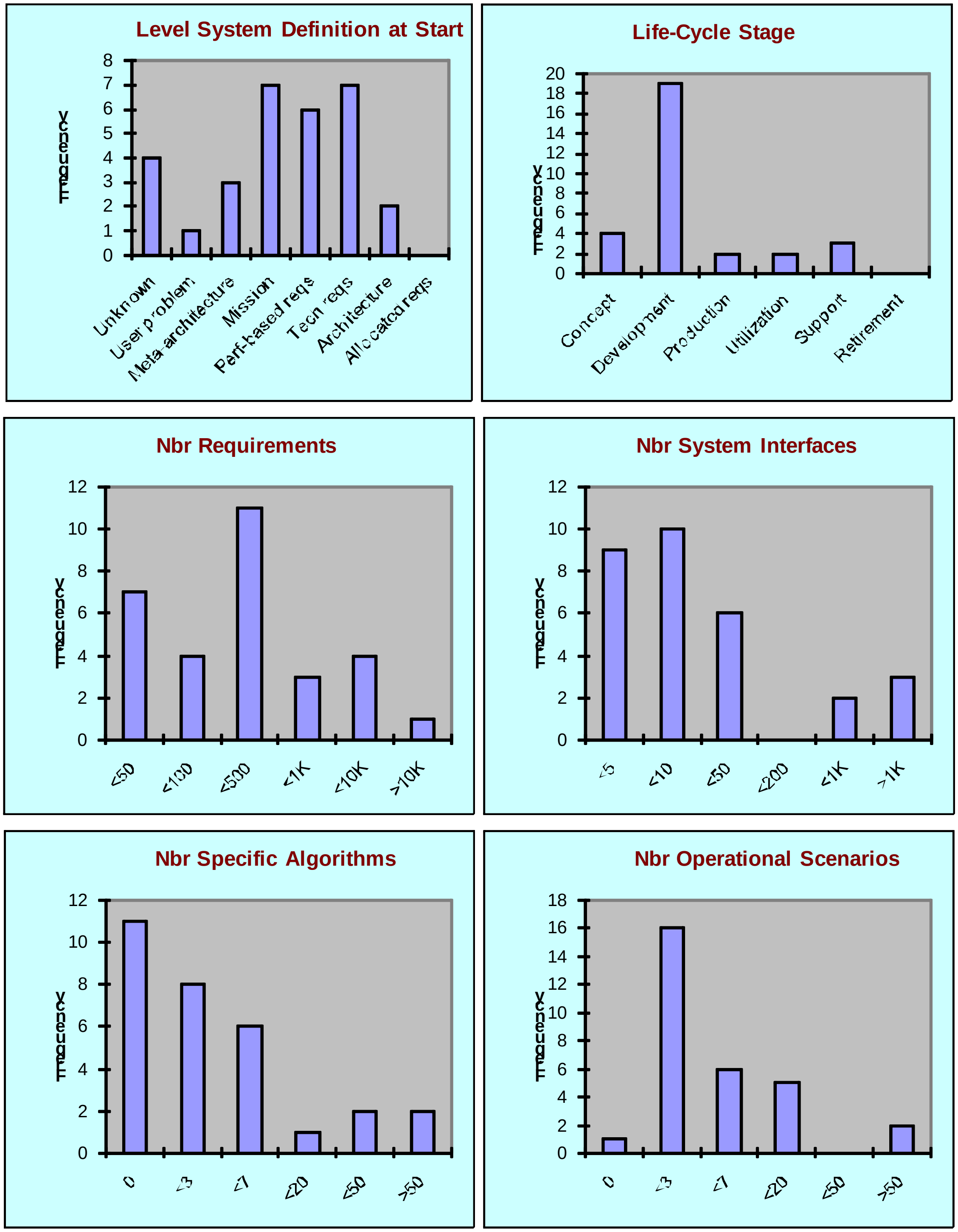

Figure 3: Source Program Size Characteristics

Systems Engineering Demographics

Of primary interest to this research is the amount of systems engineering effort used in the programs. In the "ValueSE" project, only the total systems engineering effort was obtained. In the SE-ROI project, the systems engineering effort is also categorized into eight subordinate activities.

Total Systems Engineering Effort. Figure 4 shows a histogram of the systems engineering cost as a percent of the total program cost as reported. Counts are shown for the entire data set (ValueSE and SE-ROI) and for the SE-ROI data alone. It is visually apparent that the SE-ROI data so far has been obtained from programs that use a greater level of systems engineering effort than in the ValueSE project. This is an unfortunate characteristic of the interview process, in that participating organizations have incentive to guide interviews to their better programs.

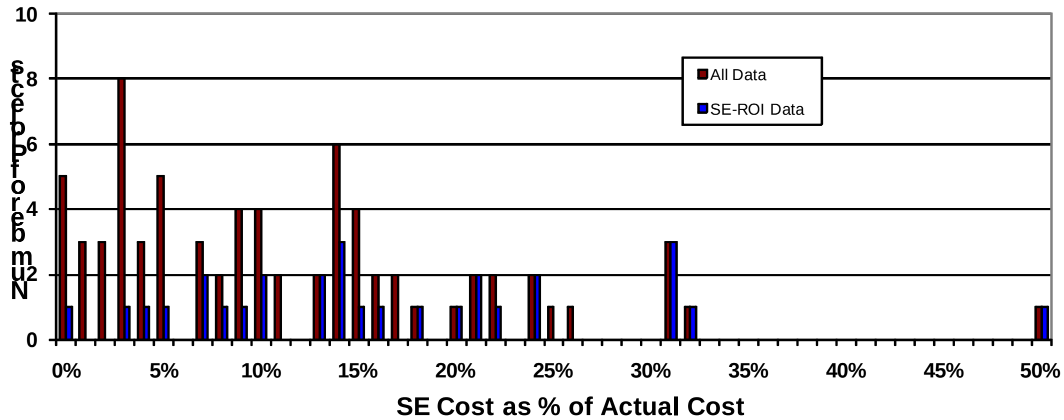

Figure 4 - Percent of Raw SE Effort by Cost[4]

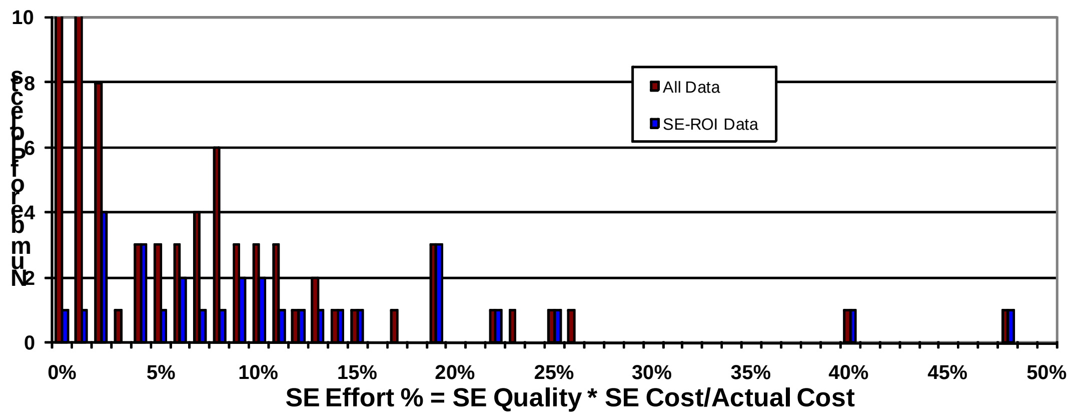

Figure 5 - Percent of Effective SE Effort by Cost

As noted in the previous work, however, it is not believed that the raw percent represents a good measure of effective systems engineering effort. This is true because the raw percent does not take into account the quality of that effort. Following the previous work therefore, we use as a primary measure the "effective SE effort" calculated by factoring the raw SE costs proportionately

[4] One SE-ROI data point at 80% SE effort is not shown. This outlier program involved a system whose components were so simple that a large part of the program effort was spent in managing the system architecting effort.

downward based on the respondents' subjective assessment of the SE quality. Figure 5 shows the histograms for the effective SE effort. It is still apparent that the SE-ROI data points so far represent a greater level of effective SE effort than the ValueSE data.

Effort by Systems Engineering Activities. Also of interest is the spread of the SE effort across the eight defined categories of SE activity. Those categories are:

- MD - 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.
- RE - 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, analyze, validate, and manage the requirements.
- SA - 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.
- SI - System Implementation. Systems engineering effort to support creation of a first functioning or prototype system that meets the defined mission or purpose. Specific system-level efforts include system integration and transition to use.
- TA - 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.
- TM - Technical Management/Leadership. Efforts to guide and coordinate the technical personnel toward the appropriate completion of technical goals. These tasks encompass elements of program 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.
- SM - 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).
- VV - Verification and Validation. Verification is the comparison of the system (or developmental artifacts) with its requirements through the use of objective evidence. Validation is the comparison of the completed system (or artifacts) with the intended mission.

Figure 6 shows the spread of program effort in the eight SE activities by cost. (This data is only available for the SE-ROI data points.) For each activity, the figure uses a range bar to show the minimum, median, and maximum levels of effort in the SE-ROI data sets. As with the overall SE effort, subjective assessments were made on each activity independently. The same data is shown in Figure 7 modified by the subjective quality of each activity.

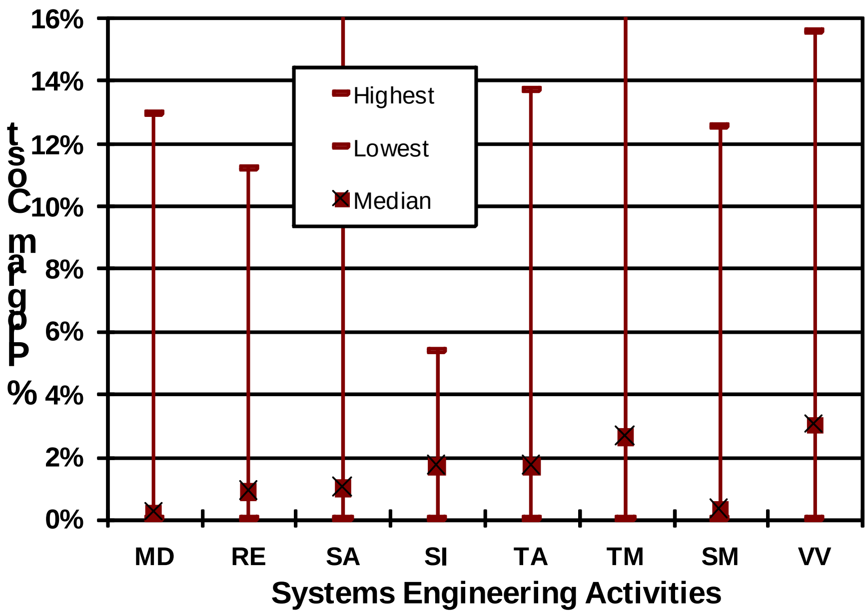

Figure 6 - Percent of Program Effort in SE Activities by Cost

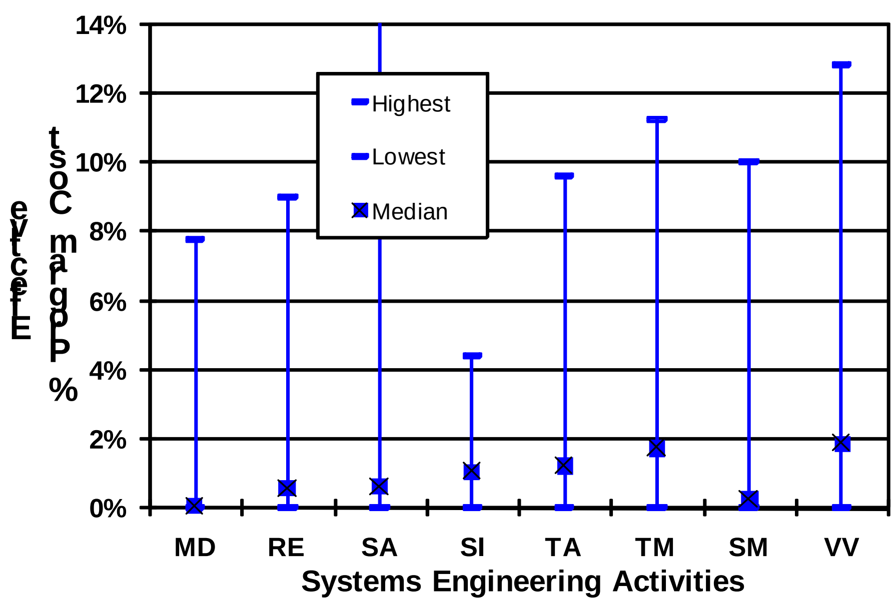

Figure 7 - Percent of Effective Program Effort in SE Activities by Cost

This data leads to a preliminary ranked order of cost of the activities, based on the median level of effort actually expended:

1. Verification/validation
2. Technical management/leadership
3. Technical analysis
4. System implementation (integration)
5. System architecting
6. Requirements engineering
7. Scope management
8. Mission/purpose definition

It should be noted that the low level of mission/purpose definition may be an aberration. Not all programs started at the same level of system definition; some programs started with a "poorly defined user problem," most started with "system mission/operations defined," and two started with "system architecture diagrams completed to next-level components." Further analysis in future reports will normalize this data.

Correlative Parameters Demographics

In the statistical correlation analysis to be performed, it is expected that the relationship between systems engineering activities and program success is modified by a series of correlative parameters. Many of these parameters are chosen to be identical to those used in the COSYSMO model (Valerdi et al. 2004), so that the correlations in this research can be later mapped to the COSYSMO parametric correlations.

In all of the demographic histograms in this section, the scale is based on subjective assessment by the interview participants, on a scale of VL=Very Low; L=Low; N=Nominal; H=High; VH=Very High.

These demographic histograms show the representative set of programs that have been selected for interview by the participating organizations. As noted above, the programs varied widely in size, capability, and success level. Programs also come from several different domains, including military, space, shipbuilding, and consumer devices.

Team Understanding. Several parameters shown in Figure 8 relate to the degree to which the development team understood, during the development, the problem to be solved. It can be seen that the participants believed their teams generally to have better-than-average understanding of the mission/purpose, requirements, and architecture. As noted above, this may be a result of the interview process, in which participating organizations tend to select better programs for interviews.

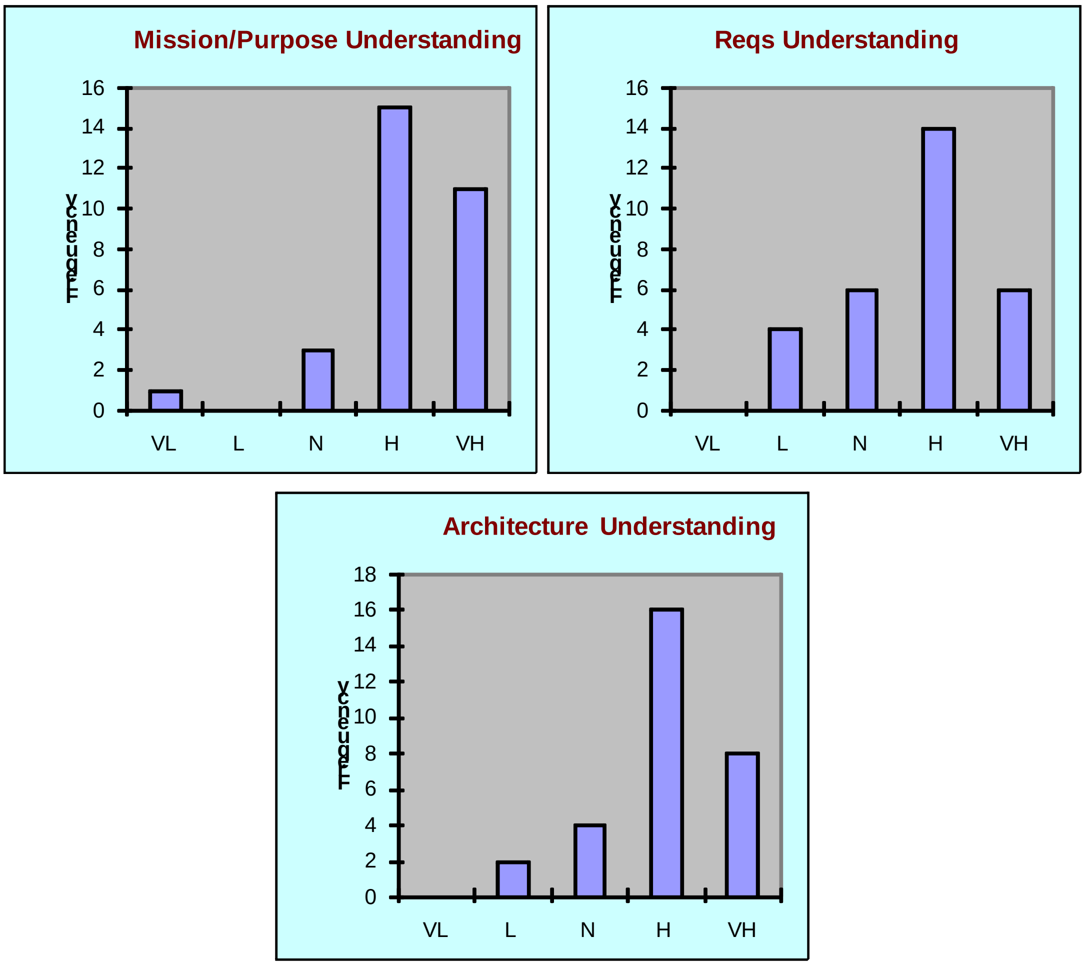

Figure 8 – Team Understanding of the Problem

Problem Difficulty. Parameters shown in Figure 9 relate to the difficulty of the problem to be solved, in terms of risk, changeability, and complexity. These parameters appear to be better balanced than the "team understanding" parameters, with near-Normal distribution in each parameter.

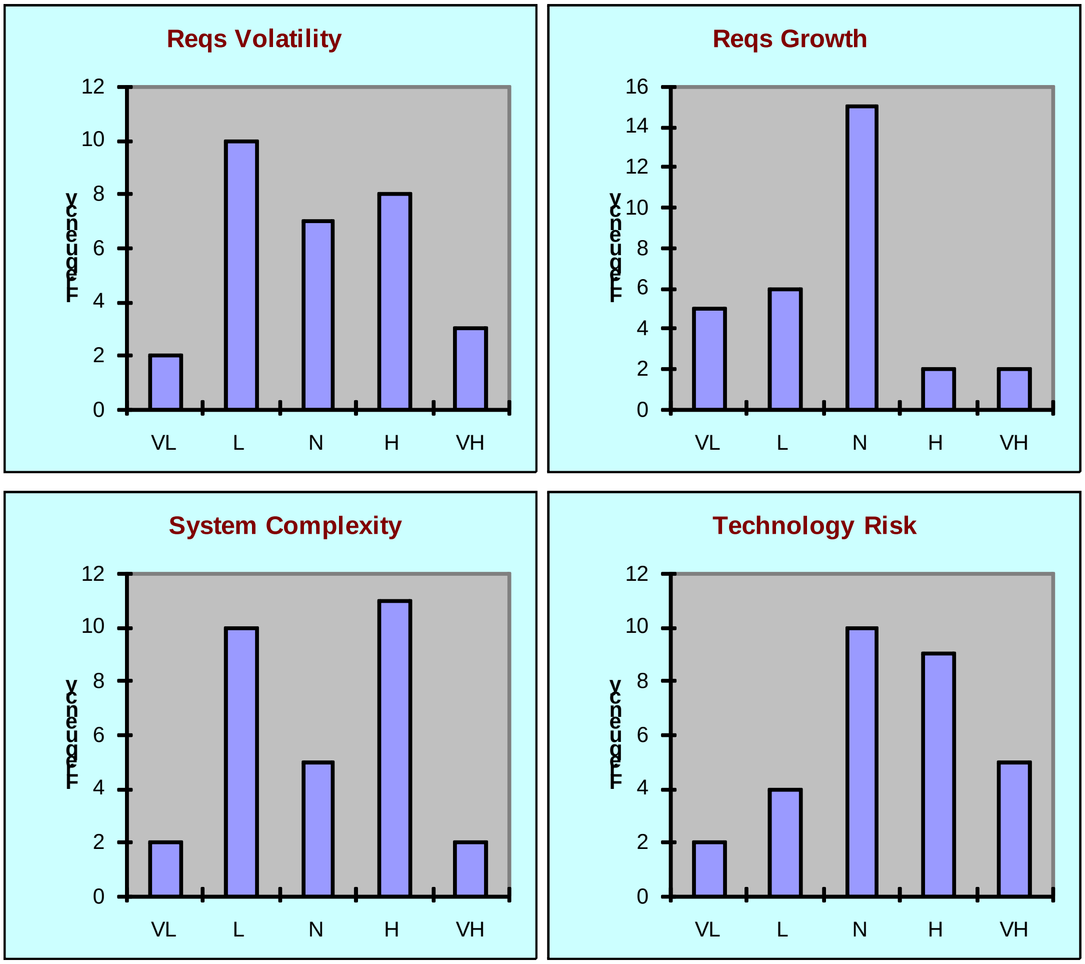

Figure 9 –Problem Difficulty

Team Capability and Experience. Parameters shown in Figure 10 relate to the general capability and experience of the development team or key individuals. Again, as with “team understanding,” participants believed their team capability and experience to be generally above average. In one exception, however, the interviewed programs acknowledged lower-than-average process capability. Most of the participating organizations did not have a CMMI rating.

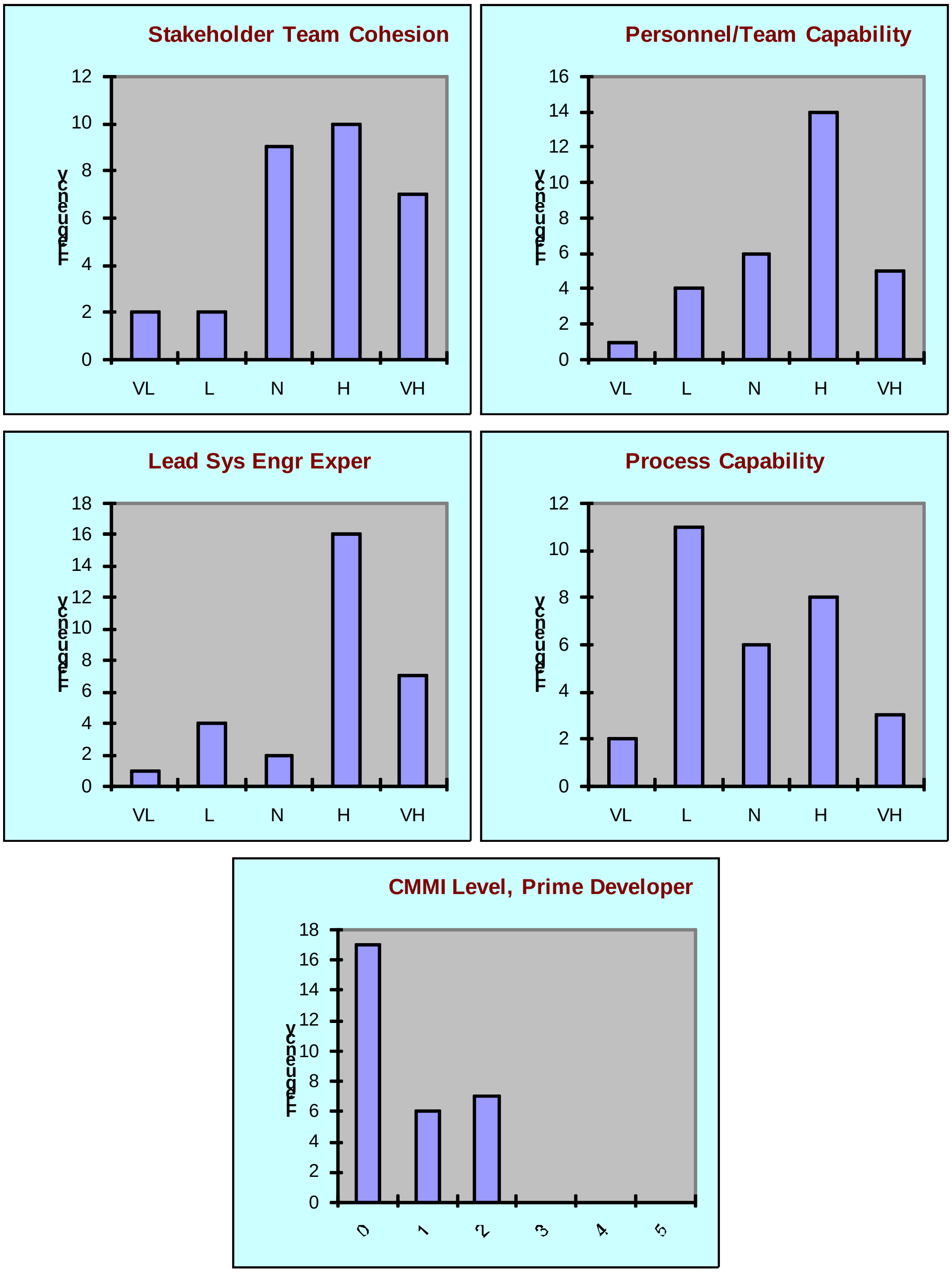

Figure 10 – Team Capability and Experience

Early Indications of Program Success

As of this publication, program interviews and statistical correlation work are continuing. Correlative information on the systems engineering ROI will be reviewed and published in future works. Some early indications, however, are already appearing. As described in (Honour 2006a), success is measured during the interviews using four measures: cost compliance, schedule compliance, technical quality against key performance parameters, and subjective product quality.

Successful and Less Successful Programs. The current data set of programs can be divided by cost compliance into two sets by selecting a level of 3% cost overrun as a point of division. There are 17 programs with less than 3% cost overrun, ranging from 38% underrun up to 1% overrun. There are 13 programs with greater than 3% cost overrun, ranging up to as much as 200% overrun. (One outlier program spent 10x the amount of the program estimates, but from qualitative interview data this was likely due to poor estimation techniques and to a slowly-funded development effort.)

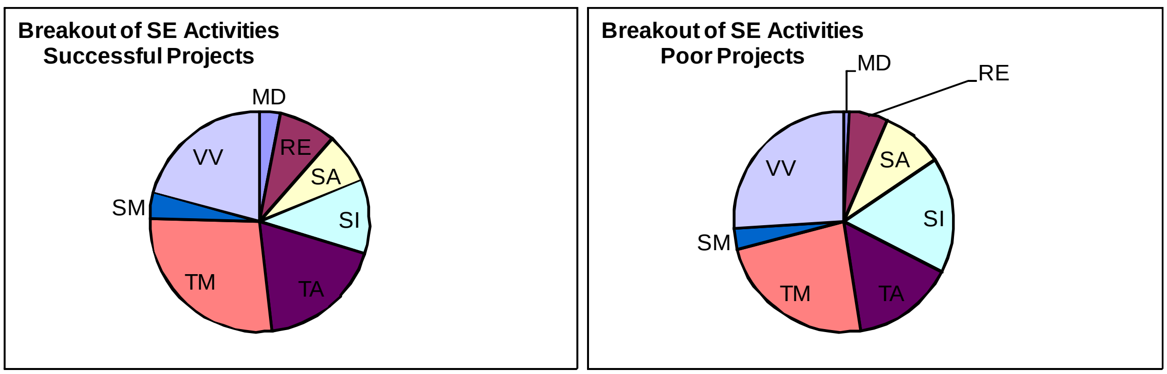

Figure 11 – Successful vs. Less Successful Programs

When the data set is divided in this way, there are some significant differences between the successful and the less successful programs. Figure 11 highlights the differences by showing the breakout of systems engineering effort into the eight defined activities. Codes shown on the pie charts are the same as those described earlier in this paper. Significant differences appear to be that poor programs expend:

- 50% ***less*** effort in mission/purpose definition (although this demographic may be a result of the starting point of the programs),
- 33% ***less*** effort in requirements engineering,
- 40% ***greater*** effort in system architecting (also known as system design),
- 60% ***greater*** effort in system implementation and integration,
- 33% ***less*** effort in scope management, and
- 25% ***greater*** effort in verification and validation.

These findings are consistent with the long-held anecdotal knowledge reported in (Honour 2004) that programs expending more front-end effort can expect to reduce overall cost and schedule. Problems that are not found during mission/purpose definition, scope management, and requirements engineering will come to fruition during system integration, verification, and validation.

Conclusions

This report is a first indication of the data being developed in the SE-ROI project. At this point, with program interviews and statistical correlation still in work, it is inappropriate to report on the statistical correlative findings. The demographic information in this report, however, shows that the project is attaining success in its pursuit of a wide variety of source programs. The interviewed programs provide requisite variety in parameters of size, business domain, systems engineering usage, success measures, problem difficulty, team understanding, and team capability/experience. Interviewed programs so far may be skewed toward those programs using greater systems engineering effort as compared with the prior work. The data being obtained appears compatible with prior works by the author and others, yet is extending those works into considerably more detail.

New information available in this report includes:

- Quantified demographic breakdown of systems engineering effort into eight common activities, with a ranking of those activities into apparent order of cost. Verification/validation, technical management/leadership, technical analysis, and system implementation (integration) expend considerably more effort than other activities.
- Initial comparison of successful to less successful programs shows that the poor programs expend comparatively less effort in the front-end activities (mission definition, requirements engineering) and greater effort in the later, hands-on activities (system design, system integration, and verification/validation).

This work continues. While this public report provides demographic indications, <u>participating organizations are receiving continued reports on the interim statistical analysis, as well as benchmarking reports on their interviewed programs</u>. Final public reports are anticipated over the next few years.

Acknowledgements

The SE-ROI project is funded and sponsored by Honourcode, Inc. and the Defence and Systems Institute (DASI) of the University of South Australia (UniSA). The work is being performed by the author as a part of a program leading to the Doctor of Philosophy degree.

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Biography

Eric Honour was the 1997 INCOSE President. He has been in international leadership of the engineering of systems for over 15 years, part of a 40-year career of complex systems development and operation. He was the founding Chair of the INCOSE (International Council on Systems Engineering) Technical Board in 1994 and served as Director of the Systems Engineering Center of Excellence (SECOE). He was selected in 2000 for Who's Who in Science and Technology and in 2004 as an INCOSE Founder. He is on the editorial board for *Systems Engineering*. He has been a systems engineer, engineering manager, and program manager at Harris Information Systems, E-Systems Melpar, and Singer Link, preceded by nine years as a US Naval Officer flying P-3 aircraft. He has led or contributed to the development of 17 major systems, including the Air Combat Maneuvering Instrumentation systems, the Battle Group Passive Horizon Extension System, the National Crime Information Center, and the DDC1200 Digital Zone Control system for heating and air conditioning. Mr. Honour now heads Honourcode, Inc., a training and consulting firm offering effective methods in the development of system products. Mr. Honour has a BSSE (Systems Engineering) from the US Naval Academy, MSEE from the Naval Postgraduate School, and is a doctoral candidate at the University of South Australia based on his ground-breaking work to quantify the value of systems engineering.