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Strengthening Systems Engineering Leading Indicators for Human Systems Integration Considerations – Insights from the Practitioner Community

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Abstract

Human systems integration has become increasingly important in modern systems. Accordingly, measuring its effectiveness as part of the systems engineering effort on a program is essential. This paper describes recent and ongoing research to confirm the need for human systems integration measures and guidance, including preliminary results from an industry survey. An outcome of the research is to augment the recently published guide on systems engineering leading indicators with information to encourage consideration of human systems integration as an integral part of systems engineering.

Introduction

Human Systems Integration (HSI) is defined as an interdisciplinary technical and management process for integrating human considerations within and across all system elements (INCOSE 2007). Adequate consideration of HSI early in acquisition and development leads to lower system life cycle costs, fewer accidents and a reduction of errors (Rhodes et al. 2009a). Challenges exist, however, for program leaders of system, design, development and implementation projects to predicatively assess whether HSI has been adequately addressed. Particularly in complex defense and government programs, it is difficult to determine if HSI has been sufficiently considered and executed to ensure a successful product. A six year collaborative initiative has resulted in a set of eighteen leading indicators for systems engineering aimed at providing predictive insight on programs (Roedler and Rhodes 2010). This work offers a basis for improving HSI measurement and insight.

This paper describes preliminary results from a targeted industry survey that was undertaken as part of a larger research effort to more effectively address HSI considerations through the extension of the current leading indicator set and associated guidance. The survey targets the primary users of high-level program and technical measures. The three main goals of the industry survey are: (1) confirmation of a need within the practicing community for high-level, leading, HSI measures and guidance; (2) gathering of recommendations for additional candidate leading indicators specific to HSI; and (3) gaining insights on the utility of generating an HSI instantiated subset of leading indicator measures. To date the elicitation has yielded interesting insights into the need for HSI specific measures in industry, the usefulness and practicality of proposed HSI instantiated systems engineering measures, along with recommendations for additional leading indicators.

Motivation

Human Systems Integration (HSI) focuses on the human as an integral part of the system lifecycle. Its successful application by program leadership is a critical enabler for optimizing total system performance. According to the recently published book, *HSI in System Development- A New Look*, there has been increasing pressure to reduce development cycle time for new systems, to cut staffing, and to increase automation. Realization of these items can raise the number of possible failure points within a system, and thus the need for structured HSI oversight by program management (Pew 2007).

Given the criticality of thorough and comprehensive human systems integration, it is imperative to provide leadership with predictive tools to assess the adequacy of HSI considerations. Over the past six years a collaborative research initiative has resulted in a set of eighteen systems engineering leading indicators aimed at providing predictive insight (Roedler, Rhodes et al. 2010). These leading indicators and their associated guidance have become widely used by many organizations, many of whom have contributed to the industry guide (Roedler and Rhodes 2010). While validated as useful for assessing systems engineering effectiveness (Rhodes et al. 2009a), the currently published leading indicators have had weak characterizations related to human systems integration.

What are Leading Indicators?

A leading indicator is a measure for evaluating the effectiveness of how a specific activity is applied on a program in a manner that provides information about the impacts that are likely to affect the system performance objectives. Leading indicators are designed to assist program leadership in delivering value to stakeholders, assisting in interventions and corrective actions to avoid problems, rework and wasted effort. Conventional systems engineering measures provide status and historical information. Leading indicators use an approach that draws on trend information to allow for more predictive insight (Rhodes et al. 2009a).

The eighteen leading indicators for systems engineering programmatic and technical performance, as related to good systems engineering practice have been developed and published in the second version of the guidance document, Systems Engineering Leading Indicators Guide 2.0 (Roedler, Rhodes et al. 2010). The current set of leading indicators include: Requirements Trends, System Definition Change Backlog Trend, Interface Trends, Requirements Validation Trends, Requirements Verification Trends, Work Product Approval Trends, Review Action Closure Trends, Risk Exposure Trends, Risk Handling Trends, Technology Maturity Trends, Technical Measurement Trends, Systems Engineering Staffing & Skills Trends, Process Compliance Trends, Facility and Equipment Availability Trends, Defect/Error Trends, System Affordability Trends, Architecture Trends, and Schedule & Cost Pressure Trends. The definitions and complete measurement specification for each indicator is found in the guide.

Research Method

In order to strengthen the HSI characteristics of the current set of leading indicators, it was deemed necessary by the research team to extend the research beyond existing literature and reach out to practicing experts in the field. Through this process the research team can discuss the usefulness and practicality of HSI instantiated leading indicators, elicit recommendations for additional leading indicators, and identify heuristics for their use and implementation.

An extensive elicitation effort began in Fall 2009 and is currently underway as of the publication of this paper. The design and execution of the interview survey is based on prominent methods derived from the literature (Holstien & Grubrium 2001), (Dijkstra 1987), (Houtkoop-Steenstra 2001). In accordance with research survey design practice (Fowler & Mangione 1990), an initial set of questions was developed and refined through exploratory interviews in order to ensure that the final survey instrument was comprehensive and appropriate.

Three survey objectives were developed: (1) confirmation of a need within the practicing community for high-level, leading, HSI measures and guidance; (2) recommendations for additional leading indicators specific to HSI; and (3) insights on the utility of generating a HSI-specific subset of leading indicator measures. For the latter, the concept is to have measures that are instantiated for HSI to be used as lower tier measures when a more detailed look at the measurement information is deemed necessary.

In order to minimize sampling error, that is error stemming from the fact that a sample may not be exactly the same in all respects as the population from which it was drawn, targeted participants were chosen from a broad variety of fields, industries, and experience levels (Fowler & Mangione 1990). Those being interviewed include program managers, systems engineers, and HSI subject matter experts from across the US DoD (including subcontractors), as well as practitioners in the commercial sector. The elicitation effort has been designed to target experts with a common background of experience on large systems, but in a variety of different functions (e.g., management, engineering). These multiple perspectives of a similar work experience aim to enable comprehensive results that are linked by a distinct thread (Czaja and Blair 2005).

To further reduce sampling error, participants were baselined with the same set of knowledge—a standard definition list and description of HSI's nine domains—prior to each interview. When conducting the interview standard, nondirective and neutral interviewing techniques were used (Fowler & Mangione 1990). Additionally, standard clarification responses were developed in order to minimize execution variance.

Preliminary Survey Insights

To date, a variety of recommendations have been gathered from the survey interview results, including an identified need for strong, leading HSI measures, possible additional HSI-instantiated leading indicators, utility rankings for the HSI-instantiated leading indicators, and recommended mechanisms for implementation.

When investigating the first survey objective—confirmation of a need within the practicing community for high-level, leading HSI programmatic measures and guidance—participants were asked to rank how their own organizations performed with respect to the usefulness and quality of existing HSI program measures.

In ranking these, a nine cell grid as shown in Figure 1 was used, and participants were asked to rate the amount of program HSI measures versus the usefulness of the measures. Interestingly, responses were highly divergent: seventy one percent of participants selected either "minimal and poor" organizational use of HSI measures or "just right and adequate" use, although nine options were available. Even more interesting were the industries that these stratified respondents represented. Sixty-seven percent of participants employed by commercial organizations and zero percent employed by the DoD or its subcontractors, marked "just right and adequate" for the HSI organizational measures. Conversely seventy-five percent of participants employed by the DoD and its subcontractors and zero percent of employees in the commercial sector marked that their organization's HSI measures are of "minimal and poor" amount and quality. While the data sample is presently too small to be statistically significant, the survey results appear to point to a difference.

Amount of Program HSI Metrics	**Usefulness** of Program HSI Metrics: Poor	Adequate	Excellent
Minimal			
Just Right			
Too Much			

Figure 1. Nine cell grid used in survey.

An insight that can be gleaned from this response is that inherent business structure, the relationship between design and development and the customer and user, affects the adequacy and amount of HSI measures. Respondents who work in the commercial space and selected organizational HSI measures used to be "just right" indicated that while formal HSI training was minimal, the focus on the human and its interaction with product systems was an integral and even ingrained focus of the organizational culture. Because the human-system experience directly impacts the perception of product quality, sales, and profits, managerial focus on human systems integration is second nature.

As an illustrative example, one interviewee described his experience on design and development projects for various lawn mowing vehicles and their evolution towards increased customer/user comfort, safety, and ergonomic design improvements. He described management's constant and relentless focus on measures revolving around the customer experience, and ascribed this focus to the close and tangible tie between this experience and profits.

Conversely, military and military subcontractor participants who largely selected that their organization's HSI measures were "poor and minimal", work on systems in which the customer and the user are not the same entity. Examples of this business structure are seen throughout the DoD and its contracting organizations. Interviewees in this domain discussed experiences where HSI design concerns were given low priority, "placed on the back burner", and "the first to receive funding cuts". They indicated a disparity between *customer* preferences and *user* preferences, with the prioritization given to customer preferences.

A descriptive example came from a manager of a large military systems design and development project, who described an HSI requirement that all visual displays be a minimum of nineteen inches in width. As system development progressed and the customer requested additional functionality - space became an issue, functionality was prioritized by the customer over user ergonomics, and the displays were cut in size.

Interviewees discussed that in a business structure where the customer and the user are separate, business processes are designed around the customer rather than the user. As a consequence, the organizational and cultural focus often shifts away from the user. These informal and formal organizational structures effect major system design decisions, leading to customer driven designs rather than user driven designs.

A respondent who is a manager at a large aircraft manufacturer described the process for tradespace analysis. During this process management, in conjunction with the customer, ranks the utility of various aspects of the system design and performs trade-offs between calculated utility and cost. In this particular organization *system performance* was requested by the customer to be weighted five times greater than human systems integration aspects of the design. This prioritization leads to design decisions skewed to optimize customer preferences rather than HSI related concerns.

On large system design, development and implementation projects that contain competing preferences between the customer and the user, HSI specific measures can serve as a mechanism to change inherent cultural, managerial, and organizational bias by placing a stronger focus on the user experience and well being.

Need for High Visibility and Standardized HSI Measures

The segment of experts working in organizations with a separate user-customer business model (such as typical DoD programs), expressed frustration over the existence of very minimal high-level measures, which lead to low visibility of systemic HSI concerns. This echoes a finding from the literature review previously conducted by the research team: in recent years there has been a lack of adequate guidance and measures for the optimal management of Human Systems Integration within the US Department of Defense[1].

Additionally, it was observed that most of the HSI domains receive inadequate attention while a few domains, such as safety and survivability, receive the majority of managerial attention. Not only was there a need identified for more HSI specific measures, but also for the correct balance, spanning each major domain, as applicable for the system under development.

A significant result from the survey was that each participant interviewed that had experience on large military systems strongly recommended that one or more Key Performance Parameters (KPPs) on a project be required to relate to HSI. This was viewed by all as a critical mechanism for elevating the focus and prominence of HSI concerns on a project. Participants discussed the large difference in staffing, funding, and visibility given to the HSI domains when an HSI measure had elevated KPP status. They also indicated concern that some large systems implementation projects lacked even a single high-level HSI measure. Several experts described the stark difference in funding and managerial focus of system development programs which had an HSI related executive measure required to be reported on to the customer, and those programs lacking such a measure.

Respondents also recognized that the use of HSI-related measures was not standardized, and was highly situational and dependent on management buy-in and advocacy of HSI. Participants discussed unease with the large variation from program to program of adequate HSI implementation and expressed a need for standardized managerial practices surrounding the field of HSI.

Enhancing Current Leading Indicators for HSI

When investigating the second survey objective, soliciting recommendations for additional leading indicators specific to HSI, participants provided revealing suggestions. The most prevalent suggestion (identified independently by over two-thirds of elicitation participants) was a measure indicating frequency and quality with which the end user is involved in the design review process. This suggestion is consistent with a variety of studies (e.g. Robey and Farrow 1982) that show that effective user involvement in

[1] The DoD has already recognized this inadequacy and responded with several recent initiatives and guidance to address this.

systems design yields strong benefits relative to successful human systems integration. Figure 2 shows a preliminary description of a measurement specification for this newly proposed leading indicator, including a detailed description, insights provided, proposed measures, and usage guidance.

User Involvement in Design Trends	
Information Need Description	
Information Need	Evaluate adequacy of user involvement in system design process and early consideration of Human System Integration needs. Understand growth, change, completeness and correctness of definition of the system requirements.
Measurable Concept and Leading Insight	
Measurable Concept	Evaluate the frequency and quality with which the end user is involved in the design review process.
Leading Insight Provided	1. Indicates extent to which user needs are considered in initial system design. *2.* Indicates level of programmatic focus on HSI concerns. *3.* Indicates risks of change due to poor HSI execution in architecture, design, and implementation.
Proposed Measurements	% Design Reviews involving the user = (# design reviews involving the user /total # of design reviews)*100 as a function of time % Design Reviews specifically focused on the user experience = (# design reviews conducted with the primary focus being evaluation of the user experience and HSI considerations / total # of design reviews)*100 as a function of time % Quality of users involved in the design review process = (actual # of users with the specified experience level involved in the design review process /planned # of users with the specified experience level involved in the design review process)*100 as a function of time
Indicator Specification	
Indicator Description	Line or bar graphs that show trends of user involvement in the design review process. Show thresholds of expected values based on experiential data. Show key events along the time axis of the graphs.
Decision Criteria	Investigate and, potentially, take corrective action when the user involvement in the design review process (quality or frequency) is below established thresholds, based on experiential data.
Assumptions	A typical design review process is conducted, meetings occur on a regular basis, and minutes are maintained & current.
Users	Program Manager (PM) Chief Systems Engineer (CSE) Product Managers Designers Human Systems Integration Subject Matter Experts Human Systems Integration Manager

Figure 2. Proposed HSI Leading Indicator – User Involvement in Design Trends

When investigating the third survey objective—gathering insights on the utility of generating an HSI-specific subset of leading indicator measures—the survey concluded by asking participants to evaluate and comment on a proposed leading indicators set. This set is comprised of selected indicators which are instantiated for HSI to incorporate strong HSI characteristics (Figure 3). This information has proven to be valuable, as it has aided the team in identifying measures of importance to managerial and technical teams.

The right hand column of the table below details the list of measures that were evaluated and commented on. Participants were asked to circle the "usefulness" or utility of the HSI instantiated measures, with 1 indicating low utility and 5 indicating high utility.

	Current Leading Indicator Measures	Leading Indicator Measures Instantiated for HSI Considerations
Requirements Trends	Requirements growth: ((#requirements in current baseline - # requirements in previous baseline) / (# requirements in previous baseline) * 100	HSI requirements growth: ((# HSI requirements in current baseline - # HSI requirements in previous baseline) / (# HSI requirements in previous baseline) * 100
	% requirements modified: (# Requirements modified / Total # requirements) * 100 as a function of time	HSI % requirements modified: (# Requirements modified / Total # requirements) * 100 as a function of time
System Definition Change Backlog Trends	Approval/closure rates for change requests: (# RFC approved/ # RFC submitted) * 100	Approval/closure rates for change requests related to HSI domains: (# HSI RFC approved/ # HSI RFC submitted) * 100
Interface Trends	% interface growth: ((# of interfaces in current baseline - # in previous baseline)/# in previous baseline) * 100	% HSI interface growth: ((# of HSI interfaces in current baseline - # in previous baseline)/# in previous baseline) * 100
	% interfaces modified: (# interfaces modified / total # interfaces) * 100	% HSI interfaces modified: (# HSI interfaces modified / total # HSI interfaces) * 100
Requirements Validation/verification Trends	Requirements validation rate (Rate at which requirements are validated with the customer/end user)	HSI Requirements validation rate (Rate at which HSI requirements are validated with the customer/end user)
Work Product Approval Trend	Deliverables completion rate: (number of related deliverables completed)/(total number of related deliverables)*100	HSI related deliverables completion rate: (number of HSI related deliverables completed)/(total number of HSI related deliverables)*100
Review Action Closure Trends	Closure rates: Number of action items closed over time	HSI Closure rates: Number of HSI action items closed over time
Risk Handling Trends	Evaluation of risk management program to assess whether the plan/action items have been properly executed. Measure = % risk handling actions closed on time.	Evaluation of risk management program, related to HSI, to assess whether the plan/action items have been properly executed. Measure = % risk handling actions, related to HSI, closed on time.
Staffing and Skills Trends	% of Effort (actual effort / total planned effort) - Planning vs. Actual	% of HSI Effort (actual HSI effort / total planned effort) - Planning vs. Actual
	% of Staffing per plan (actual staffing / total planned staffing) - Planned vs. Actual	% of HSI Staffing per plan (actual HSI staffing / total planned staffing) - Planned vs. Actual
Process Comp Trends	Profile of discrepancies: number of minor and major discrepancies over time.	Profile of HSI related discrepancies: number of minor and major HSI related discrepancies over time.
Technical Measurement Trends	Delta performance to meet related thresholds and objectives: Threshold performance - Actual performance.	Delta performance to meet HSI related thresholds and objectives: Threshold performance - Actual performance.

Figure 3. Selected indicators (left column) instantiated for HSI specific use (right column).

Interview results show the mean expert rating for all proposed indicators fell within the 3 – 4 range, indicating medium or better utility for each. However, the level of disagreement among experts surrounding the utility of two indicators (Requirements Trends and Process Compliance Trends) was relatively higher than the rest of the indicator set, based on a coefficient of variation calculation. These preliminary results indicate that the utility of the leading indicators instantiated for HSI (Figure 3) is highly situation specific and dependent on individual project needs. Rather than substituting the above modified measures for the current leading indicators set, the research team recommends communicating these to the practicing community as a HSI-instantiated subset within the leading indicator guidance material, to be used as applicable to program specific needs and gaps.

In combining elicitation results, two themes emerge from participants' comments. First, several of the measures would be more useful if the necessary data were easier to collect. Second, the difficulty in clearly defining HSI-related terms used in the measures was a common concern among participants.

It is interesting to note that when evaluating the proposed measures, each participant's functional history oriented their response. While program managers interviewed looked at the measure from the perspective of, "*what decision can I make with this?*", the HSI and Systems Engineering experts evaluated the measures from the perspective of, "*how useful is this measure in elevating HSI system issues and how difficult is it to gather the data to track this measure?*"

Conclusion

In summary, ongoing research on the development of measures for effective consideration of HSI on large system design, development and implementation programs has recently focused on executing an industry survey. Effort to date has produced several preliminary insights regarding three main objectives: (1) confirmation of a need within the practicing community for high-level, leading, HSI measures and guidance; (2) recommendations for additional leading indicators specific to Human Systems Integration; and (3) evaluation of the utility of generating an HSI-instantiated subset of leading indicator measures to provide detailed focus when required. Further, the results show significant interest in having an additional HSI specific leading indicator dealing with the amount and quality with which the user is involved in the design process.

The expert elicitation effort is continuing through June 2010 to increase the survey participant pool. Additionally the team plans to conduct a comprehensive set of interviews on a single system as a case study to look for deeper insights. In conjunction with augmenting the eighteen leading indicators in the industry guide with HSI related considerations and guidance, the research team is investigating ways to merge published guidance with heuristics uncovered through the research using a format that is easily transferrable to the practicing community.

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Biography

Kacy Gerst is a graduate student in MIT’s System Design and Management Program and a Research Assistant at the MIT Systems Engineering Advancement Research Initiative (SEAri). During summer 2009 she was an intern at the headquarters of the U.S. Department of Energy, assisting in the development of a strategic plan for the new administration. Prior to coming to MIT, Kacy spent four years holding various engineering and strategic planning positions at Sikorsky Aircraft, and one year as a consultant at Accenture. She holds her undergraduate degree in Industrial and Systems Engineering from Virginia Tech.

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