Extending Systems Engineering Leading Indicators for Human Systems Integration Effectiveness

Donna H. Rhodes, Adam M. Ross , Kacy J. Gerst, and Ricardo Valerdi

Presented by:

Dr. Donna H. Rhodes

Massachusetts Institute of Technology

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Human Systems Integration

INCOSE Definition

Human Systems Integration (HSI)

Interdisciplinary technical and management processes for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice.

US Air Force – 9 HSI Domains

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HSI Related Challenges

Example challenges leadership faces when incorporating HSI into large and complex systems:

- Identifying modes of failure or gaps early in lifecycle
- Attaining personnel with required expertise and skill sets to provide adequate coverage for each HSI domain
- Calculating HSI costs and ROI justify expenditures
- Incorporating HSI considerations into complex and multifaceted trade space evaluations
- Identifying and analyzing HSI risks throughout lifecycle
- Developing metrics to track HSI performance and indicators to predicatively assess HSI effectiveness

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Research Motivations

Consideration of Human Systems Integration (HSI) domains EARLY in acquisition and development process leads to lower system life cycle costs, fewer accidents, and a reduction of errors

HSI considerations are an integral part of the overall systems engineering process and are critically important for defense systems

Challenges exist for program leadership to predicatively assess whether HSI considerations have been adequately addressed

- *Can systems engineering leading indicators assist?*

Five year collaborative research initiative resulted in thirteen leading indicators for systems engineering aimed at providing predictive insight.

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Research Objectives

1. Augment and extend current set of systems engineering leading indicators and interpretative guidance to include considerations for HSI

2. Identify “soft indicators” for HSI effectiveness and develop guidance for program leaders

Acknowledgements

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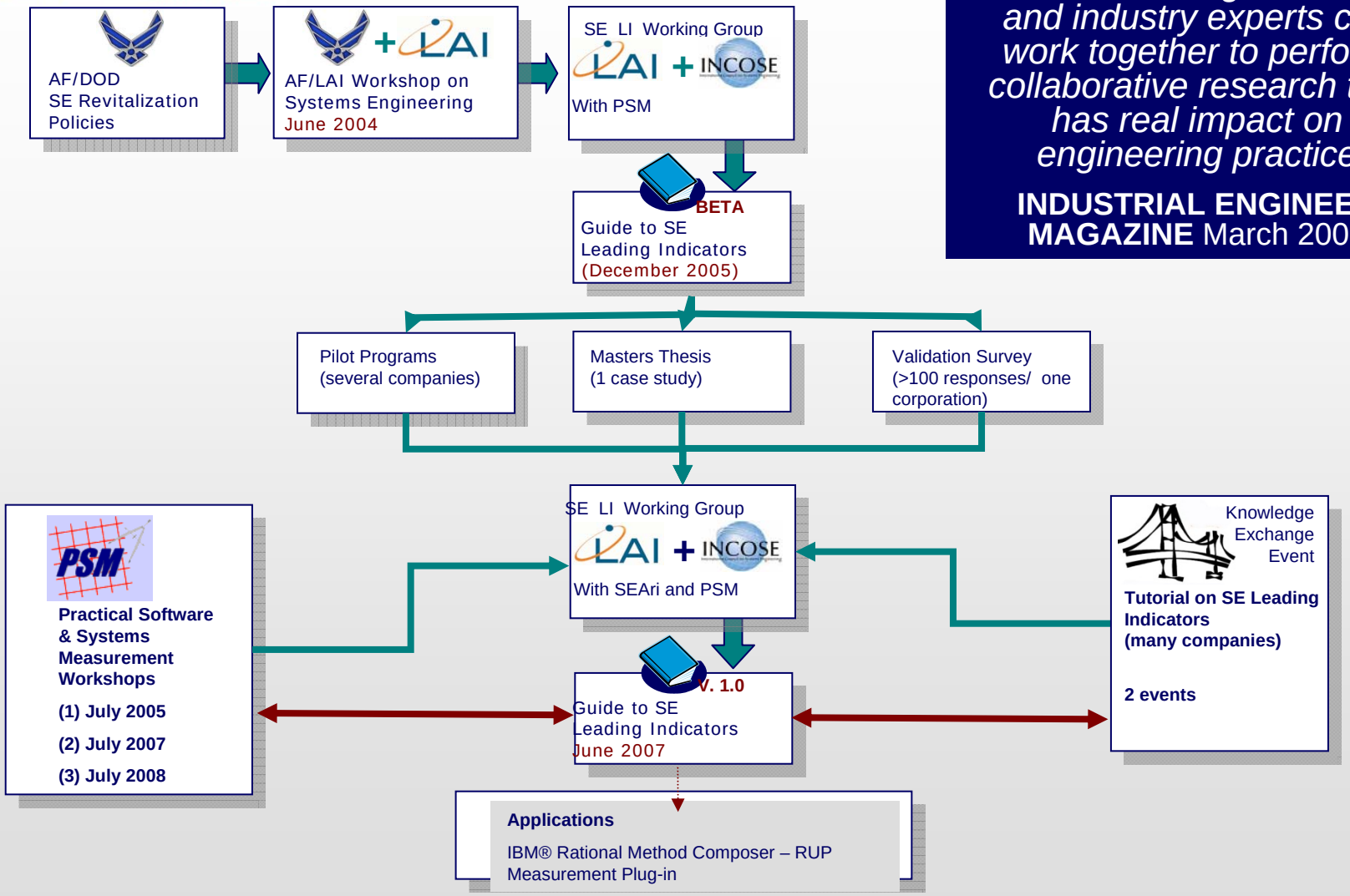
History of Project

The leading indicators project is an excellent example of how academic, government, and industry experts can work together to perform collaborative research that has real impact on engineering practice

INDUSTRIAL ENGINEER MAGAZINE March 2007



Rhodes, D.H., R. Valerdi, and J. G. Roedler, Systems engineering leading indicators for assessing program and technical effectiveness, *Systems Engineering*, 12, 21-35

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How do Leading Indicators Differ from Conventional Measures?

- Conventional measures provide status and historical information, while leading indicators use an approach that draws on trend information to allow for predictive analysis (i.e., forward looking)
- By analyzing trends, predictions can be forecast on outcomes of certain activities. Trends are analyzed for insight into both the entity being measured and potential impacts to other entities.
- This provides leaders with the data they need to *make informed decisions*, and where necessary, take preventative or corrective action during the program in a proactive manner
- While the leading indicators appear similar to existing measures and often use the same base information, *the difference lies in how the information is gathered, evaluated, and used to provide a forward looking perspective*

Roedler, G., and D. H. Rhodes, *eds.*, 2007, *Systems Engineering leading Indicators Guide* (Version 1.0), Massachusetts Institute of Technology: INCOSE and PSM.

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SE Leading Indicators

Version 1.0 Guide

- 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

Under Development for V2.0

Test Completeness Trends
Resource Volatility Trends
Complexity Change Trends
Defect and Error Trends
Algorithm and Scenario Trends
Architecture Trends

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Fields of Information in Specification for Each Leading Indicator

- **Information Need**
- **Information Category**
- **Measurable Concept**
- **Leading Insight**
- **Relationships to (Cost Schedule, Quality, etc.)**
- **Indicator**
- **Leading Information Description**
- **Usage Concept**
- **Base Measures**
- **Attributes**
- **Potential Source of Base Measures**
- **Function**
- **Derived Measures**
- **Analysis Model**
- **Decision Criteria**
- **Description of Indicator**
- **Considerations**

Based on PSM (Practical Software & Systems Measurement) and ISO 15939

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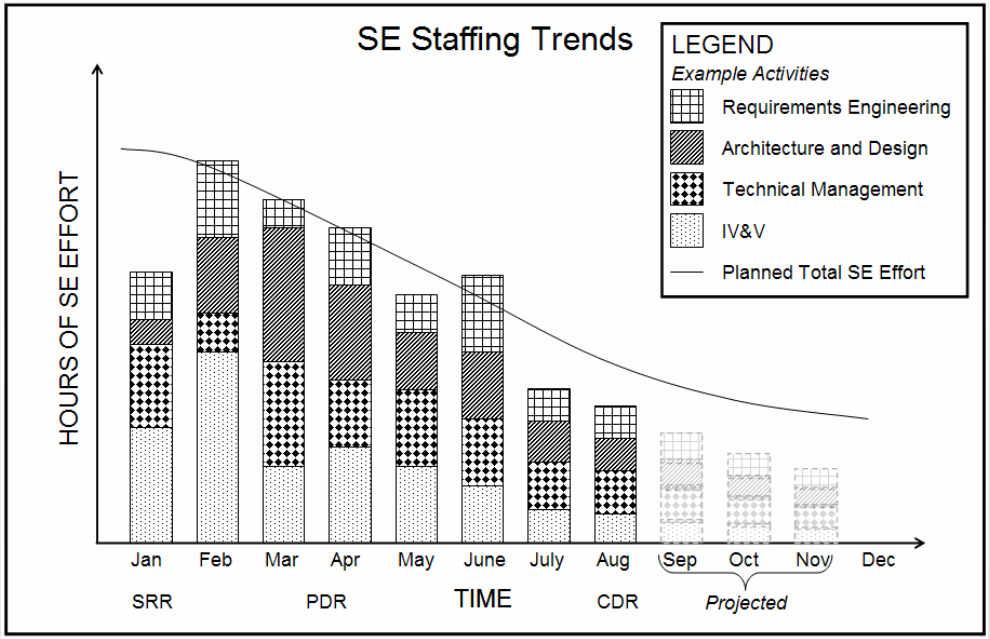
Example Indicator: Staff and Skill Trends

- Indicates whether expected level of SE effort, staffing, and skill mix is being applied throughout life cycle based on historical norms for successful projects/plans.
- May indicate gap or shortfall of effort, skills, or experience that may lead to inadequate or late SE outcomes.
- Planned staffing can be compared to projected availability through life cycle to provide an earlier indication of potential risks.

Systems Engineering Staff and Skill Trends



In this graph, effort is shown in regard to categories of activities. We see that at SRR the data would have shown actual effort was well below planned effort, and that corrective action must have been taken to align actual with planned in the next month of the project.

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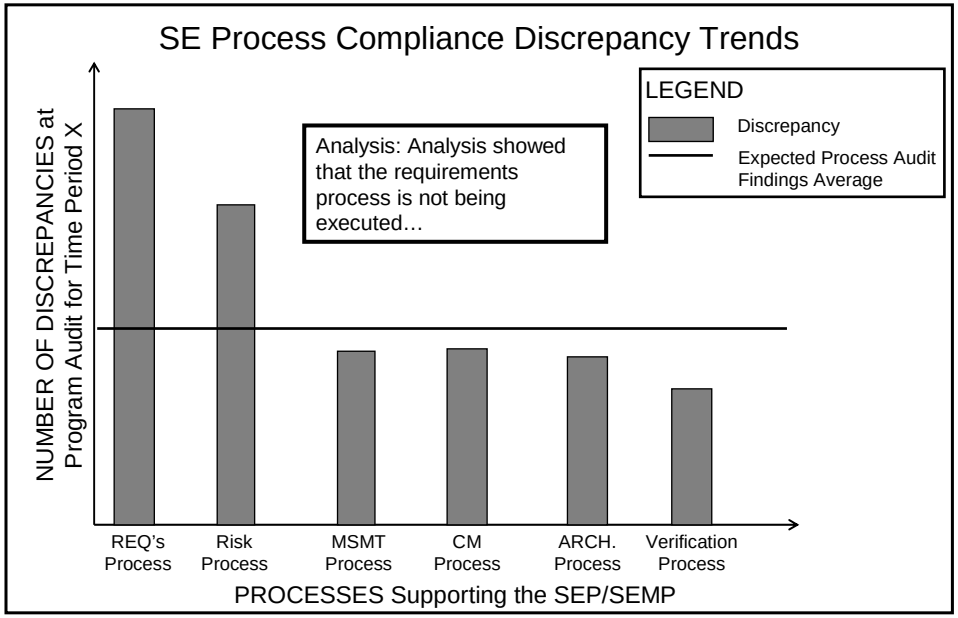
Example Indicator: Process Compliance Trends

- Used to evaluate trends in process compliance discrepancies to ensure program is within expected range for compliance.
- It indicates where process performance may impact other processes, disciplines, or outcomes of the project.
- General non-compliance indicates increased risk in ongoing process performance and potential increases in variance.
- Non-compliance of individual processes indicates a risk to downstream processes.

SE Process Compliance Trends



In this graph, discrepancies are shown in regard to categories of processes. If discrepancies are beyond expected threshold, there is an indication that there is non-compliance or possible process problems.

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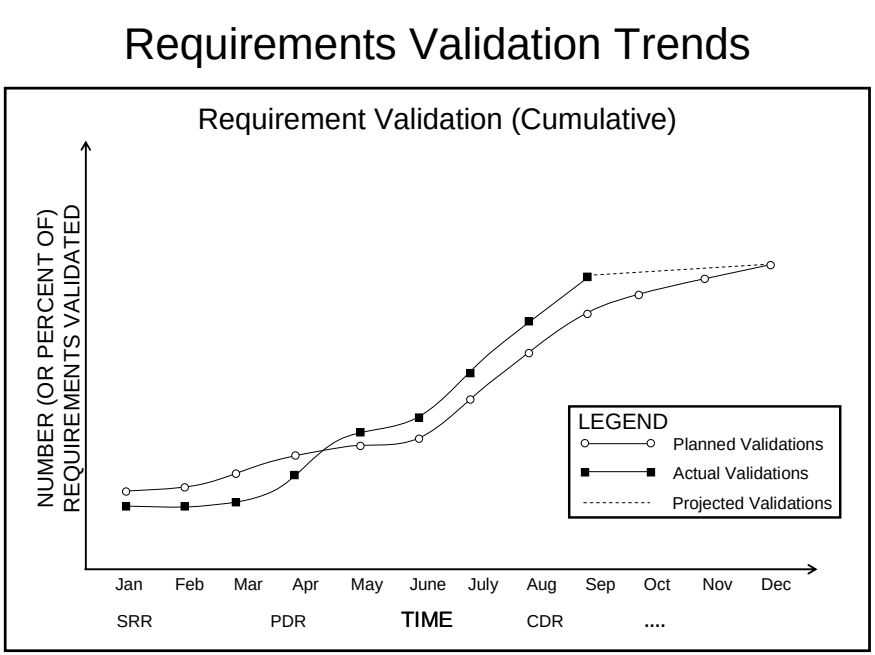
Example Indicator: Requirements Validation Trends

Illustrates the actual number of (or it could also be shown as the percent of) requirements validated versus the planned validation based on historical data and the nature of the project.

A projection will also be made based on actual validation trend.



We see at CDR that the actual validated requirements in higher than planned, indicating that the validation activity is on track.

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Requirements Validation Augmented for HSI Considerations

Requirements Validation Rate Trends	
Information Need Description	
Information Need	Understand whether requirements are being validated with the applicable stakeholders at each level of the system development.
Information Category	1. Product size and stability – Functional Size and Stability 2. Also may relate to Product Quality a performance (relative to effectivene efficiency of validation)
Measurable Concept and Leading Ins	
Measurable Concept	The rate and progress of requirements va
Leading Insight Provided	Provides early insight into level of unders customer/user needs: •Indicates risk to system definition due to understanding of the customer/user need •Indicates risk of schedule/cost overruns, changes, or user dissatisfaction

Requirements Validation Rate Trends	
Information Need Description	
HSI Considerations	***Validate with the stakeholders that, across all system elements, requirements provide significant coverage for relevant HSI domains.***
Information Need	Understand whether requirements are being validated with the applicable stakeholders at each level of the system development.
Information Category	1. Product size and stability – Functional Size and Stability 2. Also may relate to Product Quality and Process performance (relative to effectiveness and efficiency of validation) ***3. Product success relative to applicable HSI domains***
Measurable Concept and Leading Insight	
Measurable Concept	The rate and progress of requirements validation.
Leading Insight Provided	Provides early insight into level of understanding of customer/user needs: •Indicates risk to system definition due to inadequate understanding of the customer/user needs •Indicates risk of schedule/cost overruns, post delivery changes, or user dissatisfaction

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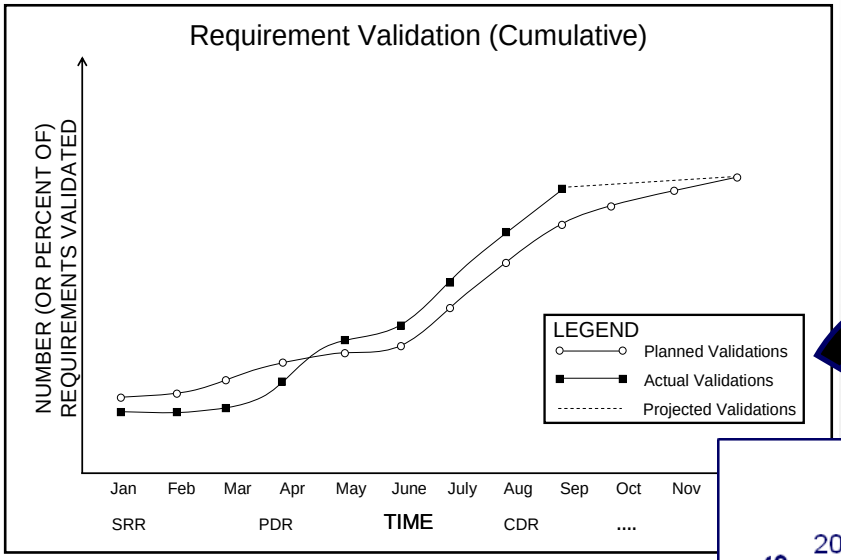
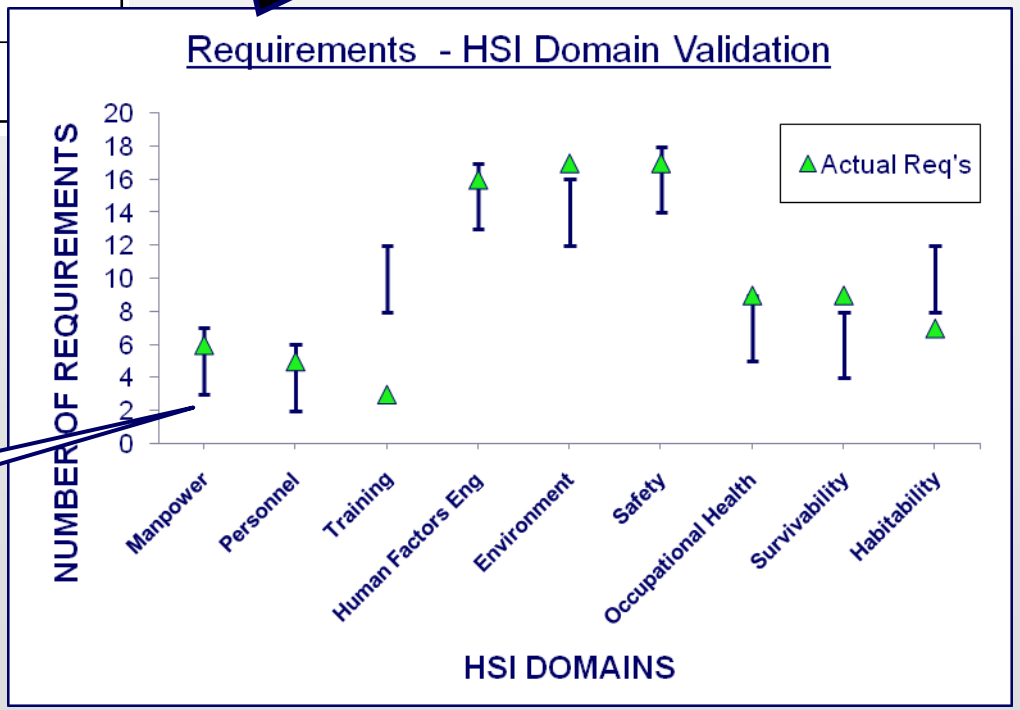
Requirements Validation Augmented for HSI Considerations





Threshold developed based on historical knowledge

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Soft Indicators for HSI Performance

Soft Indicator Definition:

- A piece of qualitative, difficult-to-measure information, whose existence indicates program success

Why is utilizing 'soft' indicators important to program leadership?

- Increases portfolio of tools available for predictive performance
- Useful when managing projects with complex situations, including multiple HSI considerations

Examples….

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Effective Allocation of Requirements to HSI Domains

- During definition of system requirements, it is important that performance and behavioral requirements for all HSI domains be adequately specified

- Potential exists for utilizing **Requirements Trend** leading indicator as a metric to monitor negative trends in requirements growth and volatility

High volatility in allocation of requirements could warrant further investigation, since requirements that are misallocated to humans (or not to humans when they should be) in the early phase can result in major issues downstream

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Impact Assessment of Allocations/Allocation Changes

- Highly effective organizations have mature process for impact assessment of requirements allocation
- Of interest is assessment of change to allocation from hardware/software to human, or human to system
- Requirements volatility, verification and validation trend indicators will be of interest, with lower level details to support investigation

Failure to assess impact of the reallocation of human systems related requirements can lead to system failures and threats to human performance, safety, etc.

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Adequacy of Stakeholder Involvement

- Within the overall footprint of HSI there are many stakeholders that require a voice in system development
- Leading indicators **Systems Engineering Staffing & Skills Trends** and **Work Product Approval Trends** potentially show whether all necessary stakeholders are in key activities

Absence of HSI personnel, particularly in early system definition activities, will likely result in inadequate consideration of HSI requirements—a precursor to system failures or down time

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Orientation for HSI in Engineering Organization

- Existence of an orientation within the engineering organization towards an HSI perspective
  - Do dedicated HSI specialists exist?
  - How much focus and priority is placed on HSI training and considerations?

Highly effective engineering teams have cognizance of each HSI domain, and the organization (customer and contractor) proactively establishes HSI related technical measurements (KPP, MOE, etc.), such as human survivability MOEs

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Adequacy of HSI Domain-specific Expertise

- HSI includes multiple domains which require unique expertise rarely found in one individual
- Indicator of less mature organization is assignment of all HSI domains to one speciality unit or specialty engineer
- Leading indicators that look at staffing in regard to coverage of HSI domains

Failure to provide adequate coverage for necessary skills and roles will likely have negative implications for performance of operational system

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Understanding Situational Factors Impacting HSI

- Factors may include severity of threat or operational environment, complexity of system interfaces, newness/precedence of system technologies, and socio-political relationship of constituents in SoS
  - For example, where a system has very complex system interfaces involving new technology and inexperienced users, the **Interface Trends** leading indicator may need to be reported and monitored on a more frequent basis

It is imperative to understand the underlying situational factors that may impact effectiveness of HSI, and how leading indicator information may be interpreted

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Research Plan

- Conduct literature review and interviews with experts (ongoing)

Currently seeking experts for interviews and recommendations for relevant case studies.

- Identify gaps in current leading indicators/indicator specifications
- Conduct case studies to identify soft indicators for HSI effectiveness (or failures)
- Perform studies – observe, collect data, analysis
- Contribute to version 2.0 of Systems Engineering Leading Indicators Guide
- Develop prescriptive information using soft indicators

Companion research on cost modelling: Liu, K., Valerdi, R., and Rhodes, D.H., "Cost Drivers of Human Systems Integration: A Systems Engineering Perspective," 7th Conference on Systems Engineering Research, Loughborough University, UK, April 2009

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Research Outcomes

Research objective: Strengthen leadership's ability to effectively utilize HSI knowledge as an integral part of the systems engineering process

The research described in this presentation will progress over an additional eighteen month period with several outcomes expected:

1. Strengthen definition and guidance for thirteen leading indicators previously developed, as well as the six proposed leading indicators
   - Results of these two areas of contribution will be incorporated into Version 2.0 of the existing guide.

2. Provide leadership guidance for ensuring soft indicators, possibly in the form of a guidance document

3. Share results of one or more case studies with the systems community through thesis and conference publications

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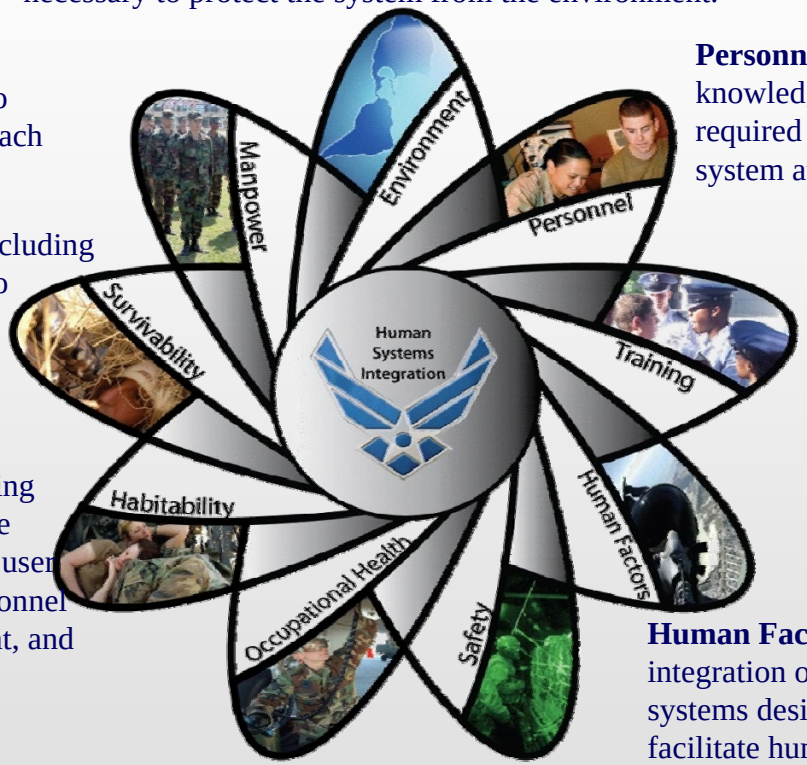
HSI in US Air Force

Environment—the conditions in and around the system and the concepts of operation that affect the human's ability to function as a part of the system as well as the requirements necessary to protect the system from the environment.

Manpower—the number and mix of personnel (military, civilian, and contractor) authorized and available to train, operate, maintain, and support each system.

Personnel—the human aptitudes, skills, and knowledge, experience levels, and abilities required to operate, maintain, and support a system at the time it is fielded.

Survivability—the ability of a system, including its operators, maintainers and sustainers to withstand the risk of damage, injury, loss of mission capability or destruction.



Training—the instruction and resources required providing personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support a system.

Habitability—factors of living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the user population that contribute directly to personnel effectiveness and mission accomplishment, and often preclude recruitment and retention problems.

Human Factors Engineering—the comprehensive integration of human capabilities and limitations into systems design, to optimize human interfaces to facilitate human performance in training operation, maintenance, support and sustainment of a system.

Occupational Health—the consideration of design features that minimize risk of injury, acute and/or chronic illness, or disability, and/or reduce job performance of personnel who operate, maintain, or support the system.

Safety—hazard, safety and risk analysis in system design and development to ensure that all systems, subsystems, and their interfaces operate effectively, without sustaining failures or jeopardizing the safety and health of operators, maintainers and the system mission.

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