## Report Documentation Page

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<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
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<td></td>
<td>00-00-2010 to 00-00-2010</td>
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<th>4. TITLE AND SUBTITLE</th>
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<td>Leading Indicators for Systems Engineering Effectiveness</td>
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<th>6. AUTHOR(S)</th>
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<td>Approved for public release; distribution unlimited</td>
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<td>Presented at the 22nd Systems and Software Technology Conference (SSTC), 26-29 April 2010, Salt Lake City, UT. Sponsored in part by the USAF. U.S. Government or Federal Rights License</td>
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| 14. ABSTRACT | |
|---------------| |
|               | |

| 15. SUBJECT TERMS | |
|-------------------| |
|                   | |

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Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Growing Interest in SE Effectiveness

• Questions about the effectiveness of the SE processes and activities are being asked
  - DoD
  - INCOSE
  - Others

• Key activities and events have stimulated interest
  - DoD SE Revitalization
  - AF Workshop on System Robustness
    • Questions raised included:
      - How do we show the value of Systems Engineering?
      - How do you know if a program is doing good systems engineering?
    • Sessions included SE Effectiveness measures and Criteria for Evaluating the Goodness of Systems Engineering on a Program
Background of the Systems Engineering Leading Indicators Project

“SE Leading Indicators Action Team” formed in late 2004 under Lean Aerospace Initiative (LAI) Consortium in support of Air Force SE Revitalization

The team is comprised of engineering measurement experts from industry, government and academia, involving a collaborative partnership with INCOSE, PSM, and several others

- Co-Leads: Garry Roedler, Lockheed Martin & Donna Rhodes, MIT ESD/LAI Research Group
- Leading SE and measurement experts from collaborative partners volunteered to serve on the team

The team held periodic meetings and used the ISO/IEC 15939 and PSM Information Model to define the indicators.

PSM (Practice Software and Systems Measurement) has developed foundational work on measurements under government funding; this effort uses the formats developed by PSM for documenting the leading indicators.
A Collaborative Industry Effort

... and several others
Objectives of the project

1. Gain common understanding of the needs and drivers of this initiative
2. Identify information needs underlying the application of SE effectiveness
   - Address SE effectiveness and key systems attributes for systems, SoS, and complex enterprises, such as robustness, flexibility, and architectural integrity
3. Identify set of leading indicators for SE effectiveness
4. Define and document measurable constructs for highest priority indicators
   - Includes base and derived measures needed to support each indicator, attributes, and interpretation guidance
5. Identify challenges for implementation of each indicator and recommendations for managing implementation
6. Establish recommendations for piloting and validating the new indicators before broad use
SE Leading Indicator Definition

- A measure for evaluating the effectiveness of a how a specific SE activity is applied on a program in a manner that provides information about impacts that are likely to affect the system performance objectives
  - An individual measure or collection of measures that are predictive of future system performance
    - Predictive information (e.g., a trend) is provided before the performance is adversely impacted
  - Measures factors that may impact the system engineering performance, not just measure the system performance itself
  - Aids leadership by providing insight to take actions regarding:
    - Assessment of process effectiveness and impacts
    - Necessary interventions and actions to avoid rework and wasted effort
    - Delivering value to customers and end users
Leading Indicators

Sources of ignition

Engineering Capability

Smoke detectors

Engineering Performance

Fire alarms

Engineering Status

Fires

Financial Indicators

Causes

Need to monitor drivers and triggers

Performance not meeting plans

Product not maturing fast enough

Behind schedule, unpredictable

Consequences

(Copyright 2009, YorkMetrics)
Interactions Among Factors

- Functional Size
- Technology Effectiveness
- Product Size
- Effort
- Customer Satisfaction
- Schedule
- Process Performance
- Product Quality

Adapted from J. McGarry, D. Card, et al., *Practical Software Measurement*, Addison Wesley, 2002
Criteria of Leading Indicators

- Early in activity flow
- In-process data collection
- In time to make decisions
  - Actionable
  - Key decisions
- Objective
- Insight into goals / obstacles
- Able to provide regular feedback
- Can support defined checkpoints
  - Technical reviews, etc.
- Confidence
  - Quantitative (Statistical)
  - Qualitative
- Can clearly/objectively define decision criteria for interpretation
  - Thresholds
- Tailorable or universal

Used criteria to prioritize candidates for inclusion in guide
Objective: Develop a set of SE Leading Indicators to assess if program is performing SE effectively, and to enhance proactive decision making.

- Thirteen leading indicators defined by SE measurement experts
- Beta guide released December 2005 for validation
  - Pilot programs conducted
  - Workshops conducted
  - Survey conducted
    - 106 responses
    - Query of utility of each indicator
    - No obvious candidates for deletion
- Version 1.0 released in June 2007
- Version 2.0 released in Feb 2010
  - Enhancements and lessons learned
  - 5 additional leading indicators

**SYSTEMS ENGINEERING LEADING INDICATORS GUIDE**

*Version 2.0*

January 29, 2010
Supersedes Initial Release, June 2007

Developed and Published by Members of

INCOSE Technical Product Number: INCOSE-TP-2010-001-03
**List of Indicators (Original Set)**

- **Requirements Trends** (growth; correct and complete)
- **System Definition Change Backlog Trends** (cycle time, growth)
- **Interface Trends** (growth; correct and complete)
- **Requirements Validation Rate Trends** (at each level of development)
- **Requirements Verification Trends** (at each level of development)
- **Work Product Approval Trends**
  - Internal Approval (approval by program review authority)
  - External Approval (approval by the customer review authority)
- **Review Action Closure Trends** (plan vs actual for closure of actions over time)
- **Technology Maturity Trends** (planned vs actual over time)
  - New Technology (applicability to programs)
  - Older Technology (obsolescence)
- **Risk Exposure Trends** (planned vs, actual over time)
- **Risk Handling Trends** (plan vs, actual for closure of actions over time)
- **SE Staffing and Skills Trends**: 
  - # of SE staff per staffing plan (level or skill - planned vs. actual)
- **Process Compliance Trends**
- **Technical Measurement Trends**: MOEs (or KPPs), MOPs, TPMs, and margins

*Original set had 13 Leading Indicators*
List of Indicators (added in Version 2.0)

- Facility and Equipment Availability
  (availability of non-personnel resources needed throughout the project lifecycle)
- Defect and Error Trends (defect discovery profile over time)
- System Affordability Trends
  (cost/effort/schedule/performance distributions)
- Architecture Trends (architecture process maturity, system definition maturity, architecture skills)
- Schedule and Cost Pressure
  (impact of schedule and cost challenges)
Fields of Information Collected for Each Indicator

- Information Need/Category
- Measurable Concept
- Leading Information Description
- Base Measures Specification
  - Base Measures Description
  - Measurement Methods
  - Units of Measure
- Entities and Attributes
  - Relevant Entities (being measured)
  - Attributes (of the entities)
- Derived Measures Specification
  - Derived Measures Description
  - Measurement Function
- Indicator Specification
  - Indicator Description and Sample
  - Thresholds and Outliers
  - Decision Criteria
  - Indicator Interpretation
- Additional Information
  - Related SE Processes
  - Assumptions
  - Additional Analysis Guidance
  - Implementation Considerations
  - User of the Information
  - Data Collection Procedure
  - Data Analysis Procedure

Derived from measurement guidance of PSM and ISO/IEC 15939, Measurement Process
1. About This Document

2. Executive Summary
   • Includes mapping of indicators to life cycle phases/stages

3. Leading Indicators Descriptions
   • Description of each indicator, example graphics, and detailed definitions with all fields of information

4. Implementation Considerations
   • Includes Cost-Benefit, Leading Indicator Performance, Composite Indicators, Mapping to SE Activities

5. References

Appendices
• NAVAIR Applied Leading Indicator Implementation
• Human Systems Integration Considerations
• Early Identification of SE-Related Program Risks

- http://www.incose.org/ProductsPubs/products/seleadingindicators.aspx
- http://www.psmsc.com
1.1 Requirements Trends

This indicator is used to evaluate the trends in the growth, change, completeness and correctness of the definition of the system requirements. This indicator provides insight into the rate of maturity of the system definition against the plan. Additionally, it characterizes the stability and completeness of the system requirements which could potentially impact design, production, operational utility, or support.

The interface trends can also indicate risks of change to and quality of architecture, design, implementation, verification, and validation, as well as potential impact to cost and schedule.

An example of how such an indicator might be reported is show below. Refer to the measurement information specification below for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

**Requirements Trends**

The graph illustrates growth trends in the total number of active requirements in respect to planned number of requirements (which is typically based on expected value based on historical information of similar projects as well as the nature of the project). The measures shown could apply to all levels of abstraction from high-level to detailed requirements. Based on actual data, a projected number of requirements will also be shown on a graph. In this case, we can see around PDR that there is a significant variance in actual versus planned requirements, indicating a growing problem. An organization would then take corrective action – where we would expect to see the actual growth move back toward the planned subsequent to this point. The requirements growth is an indicator of potential impacts to cost, schedule, and complexity of the technical solution. It also indicates risks of change to and quality of architecture, design, implementation, verification, and validation.
Example of Section 3 Contents (Cont’d)

### Requirements Trends

**Information Need Description**
- Evaluate the stability and adequacy of the requirements to understand the risks to other activities towards providing required capability, on-time and within budget.
- Understand the growth, change, completeness and correctness of the definition of the system requirements.

**Information Need**
- Product size and stability - Functional Size and Stability
- Also may relate to Product Quality and Process Performance (relative to effectiveness and efficiency of validation)

**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)

**Measurable Concept and Leading Insight**
Is the SE effort driving towards stability in the System definition and size?

- Indicates whether the system definition is maturing as expected.
- Indicates risks of change to and quality of architecture, design, implementation, verification, and validation.
- Indicates schedule and cost risks.
- Greater requirements growth, changes, or impacts than planned or lower closure rate of TBDs/TBRs than planned indicate these risks.
- May indicate future need for different level or type of resources/skills.
- Indicates potential lack of understanding of stakeholder requirements that may lead to operational or supportability deficiencies.

### Base Measure Specification

**Base Measures**
1. Requirements Trends
2. Requirement TBD
3. Requirement Defect
4. Requirement Change
5. Requirement Change

**Measurement Methods**
1. Count the number of requirements of interest (e.g., Priority Levels, Current Times)
2. Count the number of attributes of interest (e.g., Priority Levels, Current Times)
3. Count the number of requirements of interest (e.g., Priority Levels, Current Times)
4. Count the number of requirements of interest (e.g., Priority Levels, Current Times)
5. Estimate the impact

**Unit of Measurement**
1. Requirements
2. Requirement TBDs/TBRs per associated attributes
3. Requirement Defects per associated attributes
4. Requirement Changes per associated attributes
5. Requirement Closure per Requirement Change (hours expected for each change)

**Entities and Attributes**
- Requirements
- Requirement TBDs/TBRs
- Requirement Defects
- Requirement Changes
- Additional attributes including but not limited to Stakeholder Requirements, Requirements Analysis, Architectural Design
- Disposition Action, Maturity States, Priority Levels, Current Times

**Derived Measure Specification**
1. % Requirements Approved
2. % Requirements Growth
3. % Requirements Closure per Plan
4. % Requirements Modified
5. Estimated Impact of Requirements Changes for a given time interval (in Effort Hours)
6. Cycle time for Requirement Changes (each and average)
7. Requirement Defect Profile
8. Requirement Defect Density
9. Requirement Defect Leakage (or Escapes)

**Additional Information**
- Stakeholder Requirements, Requirements Analysis, Architectural Design
- Disposition Action, Maturity States, Priority Levels, Current Times

**Data Analysis**
- May also be helpful to track trends based on severity of changes
- Defect leakage - identify the phases in which defects were inserted and found for each defect recorded.

**Implementation Considerations**
- Requirements that are not at least at the point of a draft baseline should not be counted.
- Usage is driven by the correctness and stability of requirements definitions.
- Lower stability means higher risk of impact to other activities and other phases, thus requiring more frequent review.
- Applies throughout the life cycle, based on risk.
- Track this information per baseline version to track the maturity of the baseline as the system definition evolves.
### Systems Engineering Leading Indicators Application to Life Cycle Phases/Stages

<table>
<thead>
<tr>
<th>Leading Indicator</th>
<th>Insight Provided</th>
<th>Phases / Stages</th>
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<tbody>
<tr>
<td>Requirements Trends</td>
<td>Rate of maturity of the system definition against the plan. Additionally, characterizes the stability and completeness of the system requirements which could potentially impact design and production.</td>
<td>P1 P2 P3 P4 P5 S1 S2 S3 S4 S5</td>
</tr>
<tr>
<td>System Definition Change Backlog Trend</td>
<td>Change request backlog which, when excessive, could have adverse impact on the technical, cost and schedule baselines.</td>
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<tr>
<td>Interface Trends</td>
<td>Interface specification closure against plan. Lack of timely closure could pose adverse impact to system architecture, design, implementation and/or V&amp;V any of which could pose technical, cost and schedule impact.</td>
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</tr>
<tr>
<td>Requirements Validation Trends</td>
<td>Progress against plan in assuring that the customer requirements are valid and properly understood. Adverse trends would pose impacts to system design activity with corresponding impacts to technical, cost &amp; schedule baselines and customer satisfaction.</td>
<td></td>
</tr>
<tr>
<td>Requirements Verification Trends</td>
<td>Progress against plan in verifying that the design meets the specified requirements. Adverse trends would indicate inadequate design and rework that could impact technical, cost and schedule baselines. Also, potential adverse operational effectiveness of the system.</td>
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<tr>
<td>Work Product Approval Trends</td>
<td>Adequacy of internal processes for the work being performed and also the adequacy of the document review process, both internal and external to the organization. High reject count would suggest poor quality work or a poor document review process each of which could have adverse cost, schedule and customer satisfaction impact.</td>
<td></td>
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<tr>
<td>Review Action Closure Trends</td>
<td>Responsiveness of the organization in closing post-review actions. Adverse trends could forecast potential technical, cost and schedule baseline issues.</td>
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## Indicator’s Usefulness for Gaining Insight to the Effectiveness of Systems Engineering

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<tr>
<th>Indicator</th>
<th>Critically Useful</th>
<th>Very Useful</th>
<th>Somewhat Useful</th>
<th>Limited Usefulness</th>
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* Defined on the Slide. **Somewhat Useful**  |  | **Very Useful**

Note: Reflects Version 1 indicators only

Percentages shown are based on total survey responses. Not all indicator responses total to 100% due to round-off error or the fact that individual surveys did not include responses for every question.
Indicator’s Usefulness for Gaining Insight to the Effectiveness of Systems Engineering (2 of 2)

- Usefulness Ratings defined via the following guidelines:
  - 4.6-5.0 = Critical: Crucial in determining the effectiveness of Systems Engineering
  - 4.0-4.5 = Very Useful: Frequent insight and/or is very useful for determining the effectiveness of Systems Engineering
  - 3.0-3.9 = Somewhat Useful: Occasional insight into the effectiveness of Systems Engineering
  - 2.0-2.9 = Limited Usefulness: Limited insight into the effectiveness of Systems Engineering
  - Less than 2.0 = Not Useful: No insight into the effectiveness of Systems Engineering
Additional Information on Specific Application and Relationships

1. Cost-effective sets of Base Measures that support greatest number of indicators
2. Indicators vs. SE Activities of ISO/IEC 15288
3. Application of the SE Leading Indicators for Human System Integration (HSI)
4. Application of the SE Leading Indicators for Understanding Complexity
## SELI versus SE Activities of ISO/IEC 15288

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<td>6.3.1.1 Define the project</td>
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<td>6.3.1.2 Plan the project resources</td>
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<td>6.3.1.3 Plan the project technical and quality management</td>
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<td>6.3.2 Project Assessment and Control Process</td>
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21
# Leading Indicator Affinity Table

## Table 2

| Requirements | | | | | | | | | | | | | | | | | | | | |
| System Definition Change Backlog | X | X | X | X | X | | | | | | | | | | | | | | |
| Interface | X | X | X | X | X | X | | | | | | | | | | | | | | |
| Requirements Validation | X | X | X | X | X | X | X | | | | | | | | | | | | | |
| Requirements Verification | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Work Product Approval | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Review Action Closure | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Risk Exposure | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Risk Treatment | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Technical Maturity | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Technical Measurement | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Systems Engineering Staffing & Skills | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Process Compliance | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Test Completeness | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Facility and Equipment Availability | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Defect and Error | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Algorithm/Scenario | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| System Affordability | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Architecture | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |
| Schedule and Cost Pressure | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | |

- Included in analysis of cost-effective measures – may support trade-off analysis of measures by understanding the related measures
NAVAIR Applied Leading Indicators (ALI) Methodology

- Systematically analyzes multiple data elements for a specific information need to determine mathematically valid relationships with significant correlation
  - These are then identified as Applied Leading Indicators
- Provides a structured approach for:
  - Validation of the LIs
  - Identifying most useful relationships
- Unanimous agreement to include this in the SELI guide
- NAVAIR (Greg Hein) to summarize the methodology for incorporation into the SELI Guide revision as an appendix
  - Summary will include links to any supplementary information and guidance
Interaction with SERC SE Effectiveness Measurement Project

- SE Leading Indicators Guide is pointed to from SERC SE Effectiveness Measurement (EM) project for quantitative measurement perspective

- SERC EM contribution:
  - Short-term:
    - Mapping of SE Effectiveness Measurement Framework to SE Leading Indicators (SELI)
      - 51 Criteria => Critical Success Factors => Questions => SELI
        - Critical Success Factors serve as Information Needs
        - Questions serve as Measurable Concepts
    - Mapping of 51 Criteria to SELI
    - Review to ensure consistency of concepts and terminology
  - Longer-term:
    - Work with OSD to get infrastructure in place to support data collection and analysis
      - Tie to SRCA DB (TBR)
      - May require government access and analysis
QUESTIONS?