

Leading Indicators for Systems Engineering Effectiveness

SYSTEMS ENGINEERING LEADING INDICATORS GUIDE

Version 2.0

January 29, 2010

Supersedes Initial Release, June 2007

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Developed and Published by Members of



INCOSE Technical Product Number: INCOSE-TP-2005-001-03

INCOSE Chicagoland Chapter Meeting April 2011

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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



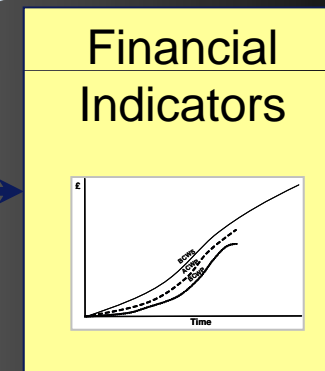
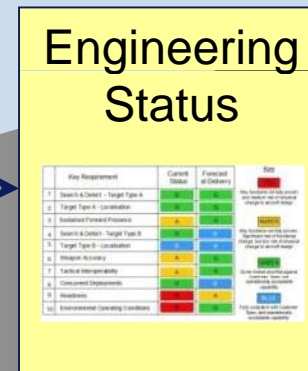
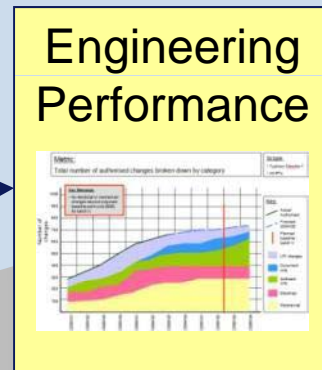
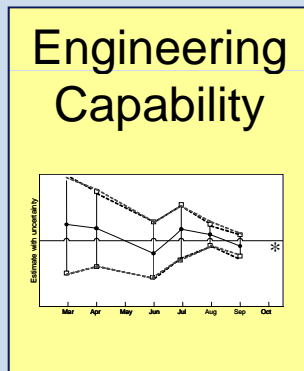
Leading Indicators

Sources of ignition

Smoke detectors

Fire alarms

Fires



Causes

Consequences

Need to monitor drivers and triggers

Performance not meeting plans

Product not maturing fast enough

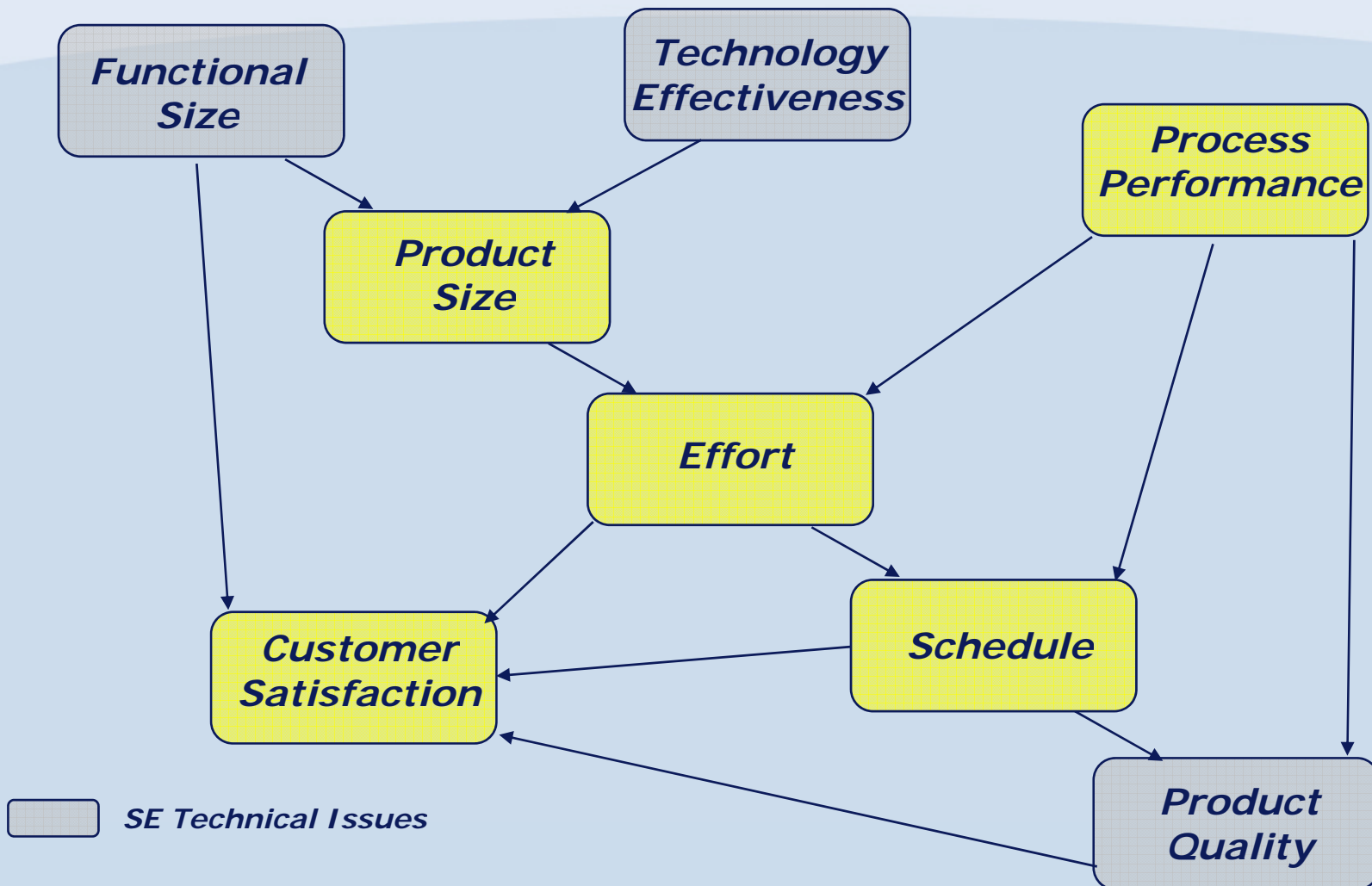
Behind schedule, unpredictable

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Interactions Among Factors



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

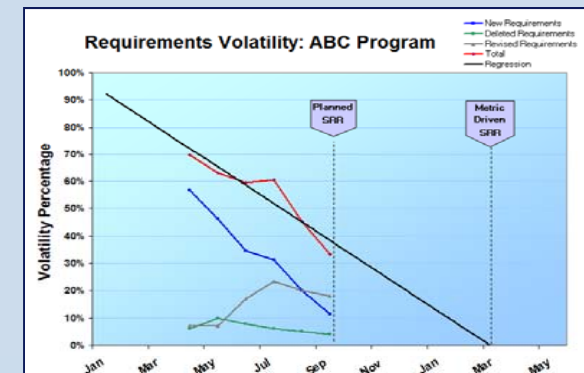
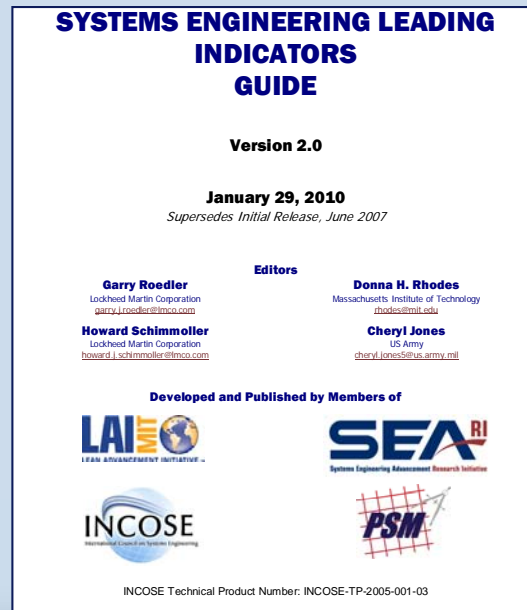
Used criteria to prioritize candidates for inclusion in guide



Systems Engineering Leading Indicators

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





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 (program applicability)
 - 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)

Version 2 Added 5 Leading Indicators



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

Guide Contents

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

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INCOSE Technical Product Number: INCOSE-TP-2005-001-03

- <http://www.incose.org/ProductsPubs/products/seleadingIndicators.aspx>
- <http://www.psmc.com>

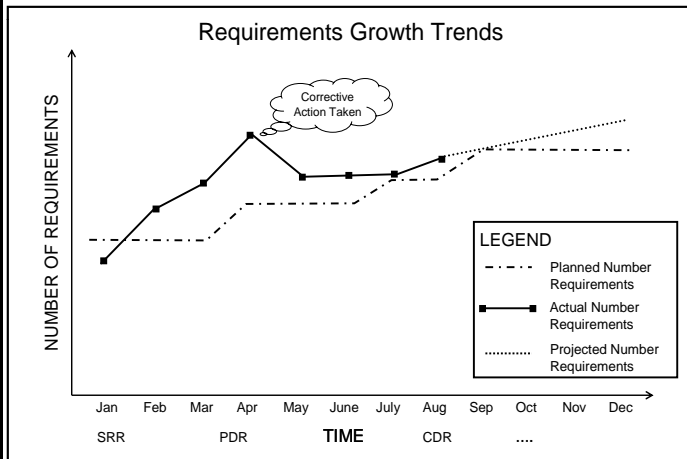
Example of Section 3 Contents

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.

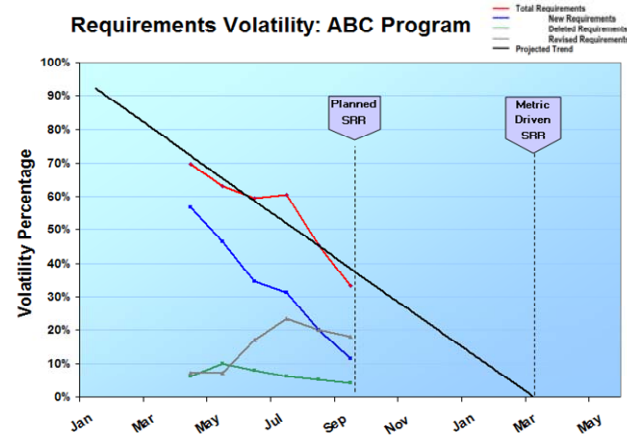
An example of how such an indicator might be reported is show below. Refer to the measurement information specification below for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational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

Requirements Trends



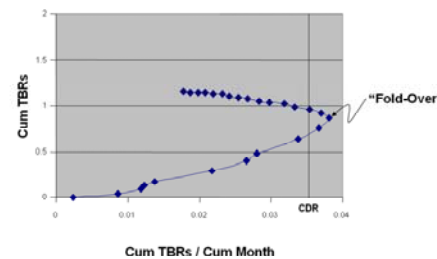
Requirements Trends. The graph illustrates growth trends in the total number of active requirements in respect to planned number of requirements (which is typically based on expected value based on historical information of similar projects as well as the nature of the project). The measures shown could 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.

Requirements Volatility: ABC Program

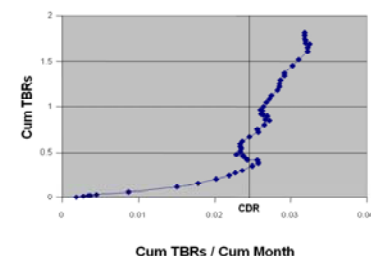


Requirements Volatility. The graph illustrates the rate of change of requirements over time. It also provides a profile of the types of change (new, deleted, or revised) which allows root-cause analysis of the change drivers. By monitoring the requirements volatility trend, the project team is able to predict the readiness for the System Requirements Review (SRR) milestone. In this example, the project team initially selected a calendar date to conduct the SRR, but in subsequent planning made the decision to have the SRR be event driven, resulting in a new date for the review wherein there could be a successful review outcome.

TBD/TBR Discovery Rate Curve



TBD/TBR Discovery Rate Curve



TBD/TBR Discovery Rate. The graphs show the cumulative requirement TBDs/TBRs vs. the ratio of cumulative TBDs/TBRs over cumulative time. Each point represents a successive instance in time as you move along the graph from bottom to top. The plot provides an indication of the convergence and stability of the TBDs/TBRs over the life cycle of the project. The graph on the left shows a desirable trend of requirement TBD/TBR stability; as the ratio of decreases and the cumulative number of TBDs/TBRs approaches a constant level. This "fold-over" pattern is the desirable trend to look for, especially in the later stages of project life cycle. In contrast, the graph on the right shows an increasing number of TBDs/TBRs even as the project approaches later stages of its life cycle; this is a worrisome trend in system design stability. An advantage of this plot is that, by shape of the graph (without having to read

Graphics are for illustrative purposes only – may reflect a single aspect of the indicator.

Indicator's Usefulness for Gaining Insight to the Effectiveness of Systems Engineering (1 of 2)

Indicator	Critical	Very Useful	Somewhat Useful	Limited Usefulness	Not Useful	Usefulness Rating *
Requirements Trends	24%	35%	11%	3%	3%	4.1
System Definition Change Backlog Trend	7	11	7	3	1	3.9
Interface Trends	14	12	4	0	1	4.3
Requirements Validation Trends	22	16	4	0	1	4.4
Requirements Verification Trends	37	23	6	2	1	4.4
Work Product Approval Trends	7	19	21	2	0	3.9
Review Action Closure Trends	5	33	21	5	0	3.9
Risk Exposure Trends	14	37	6	1	0	4.3
Risk Handling Trends	6	25	11	1	0	4.1
Technology Maturity Trends	6	6	7	0	0	4.1
Technical Measurement Trends	21	27	6	0	0	4.4
Systems Engineering Staffing & Skills Trends	11	27	15	0	0	4.2
Process Compliance Trends	6	14	11	1	0	4.0

* 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

	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	Test Completeness Trends	Resource Volatility Trends	Defect/Error Trends	Algorithm/ Scenario Trends	System Affordability Trends	Architecture Trends
6.3 Project Processes																			
6.3.1 Project Planning Process																			
6.3.1.3.a Define the project																			
6.3.1.3.b Plan the project resources												X			X				
6.3.1.3.c Plan the project technical and quality management						X	X									X			
6.3.1.3.d Activate the project																			
6.3.2 Project Assessment and Control Process																			
6.3.2.3.a Assess the project						X	X					X	X		X	X			
6.3.2.3.b Control the project						X	X					X	X		X	X			
6.3.2.3.c Close the project																			
6.3.3 Decision Management Process																			
6.3.3.3.a Plan and define decisions										X								X	
6.3.3.3.b Analyze the decision information										X								X	
6.3.3.3.c Track the decision										X								X	
6.3.4 Risk Management Process																			
6.3.4.3.a Plan Risk Management																			
6.3.4.3.b Manage Risk Profile																			
6.3.4.3.c Analyze Risks								X											
6.3.4.3.d Treat Risks								X	X										
6.3.4.3.e Monitor Risks								X	X										
6.3.4.3.f Evaluate Risk Management Process								X	X										
6.3.5 Configuration Management Process																			
6.3.5.3.a Plan configuration management																			
6.3.5.3.b Perform configuration management		X																	
6.3.6 Information Management Process																			
6.3.6.3.a Plan information management																			
6.3.6.3.b Perform information management		X																	
6.4 Technical Processes																			
6.4.1 Stakeholder Requirements Definition Process																			
6.4.1.3.a Elicit Stakeholder Requirements	X																		
6.4.1.3.b Define Stakeholder Requirements	X																X	X	
6.4.1.3.c Analyze and Maintain Stakeholder Requirements	X	X		X							X						X	X	

Leading Indicator Affinity Table

	Table 2										LEADING INDICATOR AFFINITY									
	Requirements	System Definition Change Backlog	Interface	Requirements Validation	Requirements Verification	Work Product Approval	Review Action Closure	Risk Exposure	Risk Treatment	Technical Maturity	Technical Measurement	Systems Engineering Staffing & Skills	Process Compliance	Test Completeness	Facility and Equipment Availability	Defect and Error	Algorithm/Scenario	System Affordability	Architecture	Schedule and Cost Pressure
Requirements (10)	X			X	X	X							X	X		X	X	X	X	
System Definition Change Backlog (3)	X	X	X			X														
Interface (9)		X	X	X	X	X		X	X					X		X			X	
Requirements Validation (4)	X		X	X	X				X											
Requirements Verification (9)	X		X	X	X	X				X			X	X		X	X			
Work Product Approval (5)	X	X	X		X	X						X								
Review Action Closure (3)							X		X	X				X						
Risk Exposure (6)								X	X	X				X	X			X		X
Risk Treatment (9)			X					X	X	X	X				X	X	X	X		
Technology Maturity (8)			X	X	X		X	X	X	X	X	X	X	X						
Technical Measurement (6)							X	X	X	X	X	X		X					X	
Systems Engineering Staffing & Skills (6)						X		X	X	X	X	X			X					X
Process Compliance (3)	X				X					X		X	X							
Test Completeness (11)	X		X		X		X	X		X	X			X		X	X		X	X
Facility and Equipment Availability (5)								X	X			X			X			X		X
Defect and Error (6)	X		X		X				X					X		X			X	
Algorithm/Scenario (5)	X				X				X					X			X		X	
System Affordability (5)	X							X	X						X			X		X
Architecture (6)	X		X								X			X		X	X		X	
Schedule and Cost Pressure (5)								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



Related Measurement Guidance

- INCOSE
 - Technical Measurement Guide (MOE, MOP, TPM)
 - SE Measurement Primer V2.0
 - Measurement Tools DB
 - Measurement Papers
 - URL: <http://www.incose.org>
- Practical Software and Systems Measurement (PSM)
 - Guidebook V4.0b
 - Technical Guides/Papers (Safety Measurement, Security Measurement, SW Assurance, ...)
 - PSM Training
 - URL: <http://www.psmc.com>
- Defense Acquisition University (DAU)
 - PSM-based Continuous Learning Module (online – open to all)
- ISO/IEC/IEEE Standards
 - ISO/IEC/IEEE 15939, Measurement Process
 - Standard is consistent with PSM and INCOSE products
 - ISO/IEC/IEEE 15288, System Life Cycle uses summary level info
 - URL: <http://www.iso.org> or <http://www.ieee.org>
- SEI CMMI™
 - Measurement & Analysis Process Area
 - Drew from measurement concepts in PSM and ISO/IEC/IEEE Standard

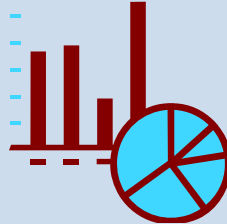
Using the SE Leading Indicators as a Source for DoD System Development Performance Measurement



Working Group Goal

Identify potential

- measures,
- indicators, and
- methods



for managing programs, particularly in support of

- making better technical decisions and
- providing better insight into technical risk

at key program milestones during

- Technology Development and
- Engineering and Manufacturing Development

for both the acquirer and supplier





Drivers

- the USD (AT&L) memo “Better Buying Power” (Sept. 14, 2010)
 - At Milestone B a “presentation of a systems engineering tradeoff analysis showing how cost varies as the major design parameters and time to complete are varied.”
 - to only conduct reviews that “support major investment decisions or to uncover and respond to significant program execution issues”
- the requirement in the Weapons Systems Acquisition Reform Act 2009 (WSARA)
 - for joint DDR&E Developmental Test and Evaluation and Systems Engineering tracking and reporting on Major Defense Acquisition Program (MDAP) achievement of measureable performance criteria
- DDR&E Imperative:
 - Reduce the cost, acquisition time and risk of our major defense acquisition programs
 - strong emphasis on understanding technical risks and trades, in the context cost and schedule
- NDIA Top Systems Engineering (SE) Issues (2010)
 - Issue #4: Decision makers do not have the right information at the right time to support informed and proactive decision making that ensures effective and efficient program planning, management and execution.



Working Group Imperatives

- Build on what has already been done
- Focus on technical measures that provide the insight needed at major decision points
- Emphasize leading/predictive measures
- Minimize the effort of data collection and analysis but improve the usage of objective performance data
- Understand impacts of the right – and wrong – measures on program effectiveness
 - Measures of cost, time, and technical performance: only measure what provides genuine insight



Expected Outcomes

- Succinct guidance on the most beneficial quantitative approaches for providing insight into technical issues
 - Informed decisions for DoD executives at key program milestones
 - Improved alignment of Industry practices with program plans
- Consideration of the impact of the life cycle on the measures utilized
- Initial recommendations on benchmarking and data repositories

Thank You !

QUESTIONS? ■

