Practical Software and Systems Measurement

Objective Information for Decision Makers

Leading Indicators for Systems Engineering Effectiveness in Digital Engineering Programs

September 17, 2019

Donna Rhodes, MIT

Motivation

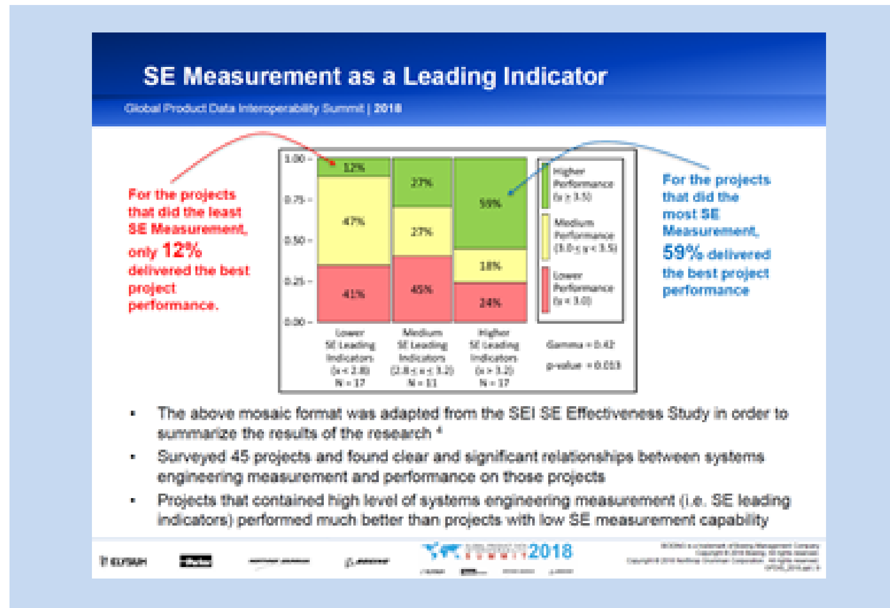
Studies demonstrate the value of mature measurement capability

State of the practice of measurement based on traditional engineering

Digital engineering is a game-changer that motivates re-examining systems engineering leading indicators

Importance of Leading Indicators

Dr. Chris Orlowski, 2018



Background

More than a decade ago, systems experts from **industry, academia and government collaborated** to develop the SE Leading Indicators Guide, aimed at predictive assessment of SE effectiveness during the program lifecycle.

The guide details **eighteen leading indicators** using the PSM measurement specification format, and provides useful measurement guidance and practitioner insights.

The guide, however, was **developed under the assumptions of traditional systems engineering**.

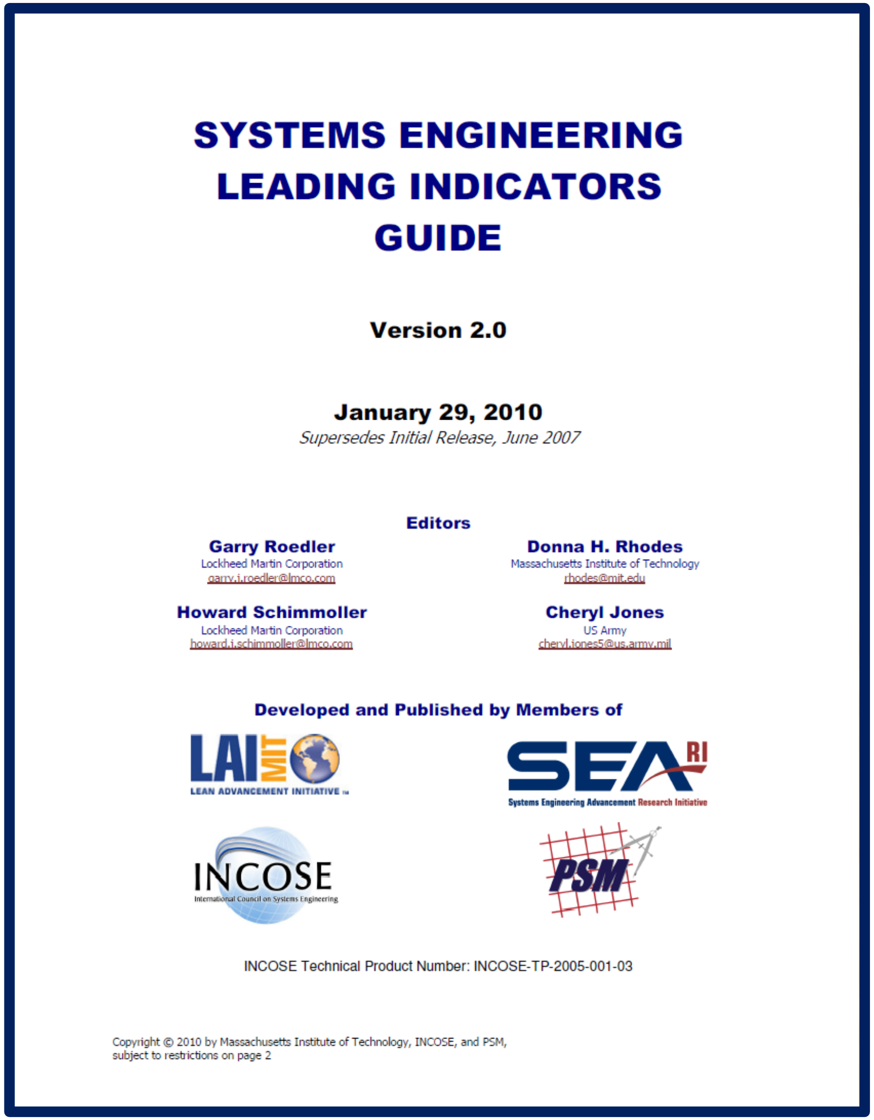
With the transformation to digital engineering, the **question arises as to whether these leading indicators are still useful and what modification may be required**.

SE Leading Indicators

Initial set of thirteen

- 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

Selected to align with metrics in use by organizations



SYSTEMS ENGINEERING
LEADING INDICATORS
GUIDE

Version 2.0

January 29, 2010

Supersedes Initial Release, June 2007

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Five additional indicators (18 total)

Applied Leading Indicator Implementation Guidance

- New Appendix A: NAVAIR's Systems Engineering Development & Implementation Center (SEDIC) use of SE leading indicators to develop advanced analysis techniques and toolkit for Navy programs
- New Appendix B: Human Systems Integration Considerations
- New Appendix C: Early Identification of Program Risks

Contributing Organizations

SE Leading Indicators Guide Version 2.0

BAE Systems
Boeing
Defense Contract Management Agency
International Council on Systems Engineering
General Dynamics
Lockheed Martin
MIT
MITRE
National Defense Industrial Association (NDIA) Systems Engineering Division (SED)
Naval Air System Command
Northrop Grumman Corporation (NGC)
Practical Software and Systems Measurement
PRICE Systems
Raytheon
Science Applications International Corporation (SAIC)
Systems Engineering Research Center
Third Millennium Systems
University of Southern California
US Air Force Center for Systems Engineering
US Army Research, RDECOM-ARDEC
US Office of Secretary of Defense

Lead Organizations

Development of Leading Indicator Measurement Specifications

3.17.1 Architecture Trend Specification

Architecture	
Information Need Description	
Information Need	Evaluates the maturity of an organization with regards to implementation and deployment of an architecture process that is based on an accepted set of industry standards and guidelines
Information Category	• Product Quality • Process Performance • Technology Effectiveness • Customer Satisfaction
Measurable Concept and Leading Insight	
Measurable Concept	• Is the process definition based on industry accepted standards? • Is SE using a defined architecture process through the leadership of certified architects? • Do the architecture work products conform to an industry accepted set of standards?
Leading Insight Provided	• Indicates whether the organization has an architectural process that will assist in maturing the system design • Indicates whether the organization has the architectural skill set in order to execute an architectural process • May indicate future need for different level or type of resources / skills • Indicates whether the system definition is maturing • Indicates schedule and cost growth risk
Base Measure Specification	
Base Measures	1. Commitment 2. Capability 3. Plans and Products 4. Performance Metrics 5. Strategic Direction 6. Interfaces and Interoperability 7. Data 8. Security
Measurement Methods	Self-assessment or independent appraisal
Unit of Measurement	Each Base Measure has an associated unitless level.
Entities and Attributes	
Relevant Entities	• Assessment levels
Attributes	• Assessor contact information • Time Interval (e.g., date, time, monthly, quarterly, phase, etc.) • Objective evidence that support the assessment levels selected • Objective evidence meta-data • Associated attributes (e.g., status, maturity - identified and defined, interval, milestone, type, cause, severity, etc.)

Architecture	
Derived Measure Specification	
Derived Measure	1. Number of base measures failing to improve over time 2. Combined base measure scores 3. Certified architects
Measurement Function	1. Number 2. Weighted average 3. Number
Indicator Specification	
Indicator Description and Sample	Line chart depicting base measures at discrete review points in time.
Thresholds and Outliers	Organization-dependent experience is needed to identify the thresholds and outliers based on comparison to historic project and system performances.
Decision Criteria	Investigate and potentially take corrective action when the base measures do not all improve over time. All measures are expected to exceed level 3 by the time that design begins.
Indicator Interpretation	Lack of progress in any base measures over several periods indicates weakness in the architecting process.
Additional Information	
Related Processes	• Technical Risk • Requirements Analysis • Modeling • Design
Assumptions	Self-assessment is performed by experts with adequate breath of experience and proven judgment.
Additional Analysis Guidance	• System architects must work with leadership, subject matter experts, and stakeholders to build an integrated view of a system's structure, strategy, processes, and information assets to perform the assessment. • Assessment experience will aid in applying the measures in a consistent manner. • Singular assessors are to be avoided whenever possible.
Implementation Considerations	• Record the metadata and examples of objective evidence that supports the base measure level selected. (This might include architecture views, and products, security standards, interface standards, etc.) These data help in recreating or reevaluating the assessments during later project phases.
User of Information	1. Program/Project Manager 2. Chief Systems Engineer 3. Chief Architect 4. Process Lead 5. Architecture Review Board
Data Collection Procedure	See Appendix F
Data Analysis Procedure	See Appendix F

Each of the eighteen leading indicators has a specification, developed through empirical investigation, for the purpose of providing guidance for implementation and interpretation.

SE Leading Indicators (2010)

Initial set of thirteen + five

- 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
- Schedule and Cost Pressure

Thinking About How Digital Engineering Impacts SE Leading Indicators (LI)

Potential approach is to use three categories to analyze how leading indicators will need to be adapted or newly created

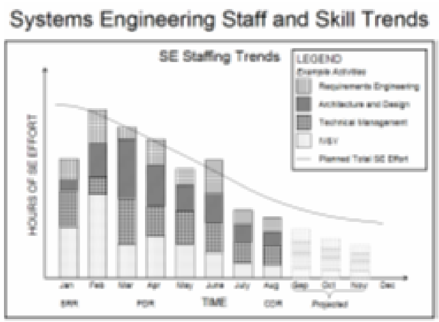
Category 1	Digital engineering has minimal impact on the leading indicator	*Additional Information* section of measurement specification augmented with descriptive information
Category 2	Digital engineering results in significant changes and additions to leading indicators measurement specification	Modify and add information to all relevant areas of the measurement specification
Category 3	Digital engineering provides opportunities for novel leading indicators	Generate new measurement specification and illustrative graphics of displayed information

Category 1 Example

Some leading indicators will have minimal impact from digital engineering

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.



In this graph, effort is shown in regard to categories of activities. We can 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.

Example of adding descriptive information to existing measurement specification

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 – Function... 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

Category 2 Example

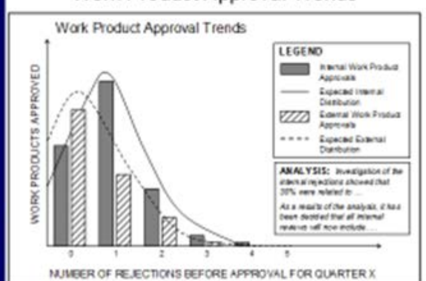
Work Product Approval Trends

Illustrates success of work product approvals for Quarter X in respect to how many rejections there were for work products before approval for both internal work product approvals and external approvals.

Actual rejections shown with overlay of expected internal and external approvals based on historical data

Analysis will be needed to understand why rejections are happening, and graphic could include breakdown of root causes as stacked bars, rather than just single bar.

Work Product Approval Trends



May be helpful to use a quad-chart or other graphical presentation techniques to look at performance on related work products

Changes would be made to many/all areas of the measurement specification

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Category 3

novel or enhanced indicators

- Collaborators working on second version of the guide identified priorities … but many were too difficult to implement under traditional engineering

- Digital engineering opens now possibilities for leading indicators

Stakeholder Priorities for Version 2.0

Actual Version 2.0 indicators

New indicators

1. Test Completeness [14]
2. Resource Volatility [13]
3. Complexity Change Trends [12]
4. **Defect and Error Trends [11]**
5. Algorithm & Scenario Trends [10]

Top 5

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6. **Architecture Trends [8]**
7. Concept Development [6]
8. SoS Capability Trends [6]
9. Productivity [6]

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10. Baseline Mgmt [3]
11. SE Index [1]
12. Product Quality [0]
13. Team Cohesion [0]
14. End-to-end Deployment [0]

Facilities & Equipment Availability
System Affordability Trends
Schedule and Cost Pressure

Current/Planned MIT Research

sponsored by Naval Postgraduate School Acquisition Research Program

ACQUISITION RESEARCH PROGRAM
NAVAL POSTGRADUATE SCHOOL

Phase 1 (2019)

Research Tasks:

- Adapt/extend LIs for Model-Based Engineering and Digital Artifacts
- Expert Assessment on Usefulness
- Illustrative Application Case
- Select publically available model-based case studies
- Show value of LIs in providing insight into program decisions

NPS Acquisition Symposium paper (May 2020) and Tech Report (Aug 2020)

Phase 2 (2020)

Research Questions:

- *How can digital engineering* ***measurement data be composed into leading indicators and displayed*** *to best enable assessment of engineering effectiveness?*

- *How can* ***leading- edge techniques*** *(automated data collection, visual analytics, etc.) be used to* ***collect and synthesize measurement data from digital artifacts*** *and environments?*

NPS Acquisition Symposium paper (May 2021) and Technical Report (Aug 2021)

Emerging …

- Model-based toolsets…potential to generate new and more extensive data and analytics
- Digital environments enable real-time access, data on demand, more context information
- Interactive dashboards more easily created and populated in real-time
- Our societal expectations for delivery of information have evolved

91% of consumers now prefer interactive and visual content over traditional, text-based or static media. **Forbes Magazine, 2018**

Composability

Composability concerns the selection of elements that can logically and reasonably be assembled.

- Requirements Trend indicators, for instance, are used to evaluate trends in the growth, change, completeness and correctness of the definition of system requirements
- Traditional engineering: requirements are central objects used for assessing maturity of system definition
- MBSE - there are requirements diagrams, use case diagrams, activity diagrams, state machine diagrams, parametric diagrams, and others.

With model-based measurement data, the question arises as to which measureable data elements can be composed into leading indicators for engineering effectiveness in model-based acquisition programs.

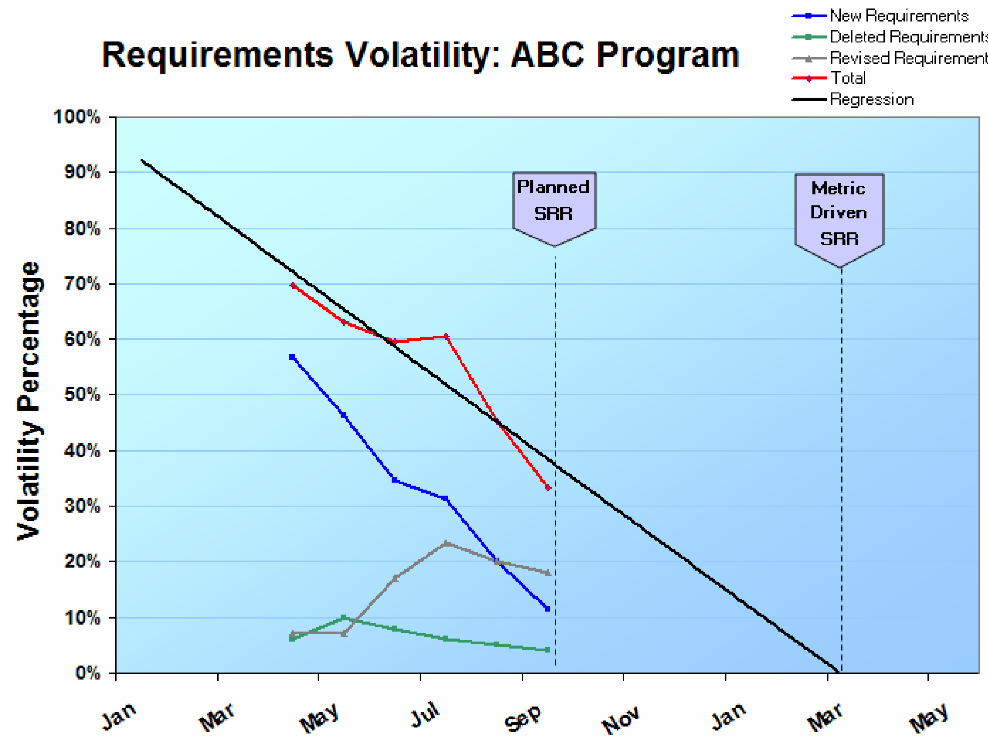
Traditional engineering: What is an example of how leading indicators have contributed to effective systems engineering on a program?

By monitoring requirements validation trend, team was able to more effectively predict SRR readiness

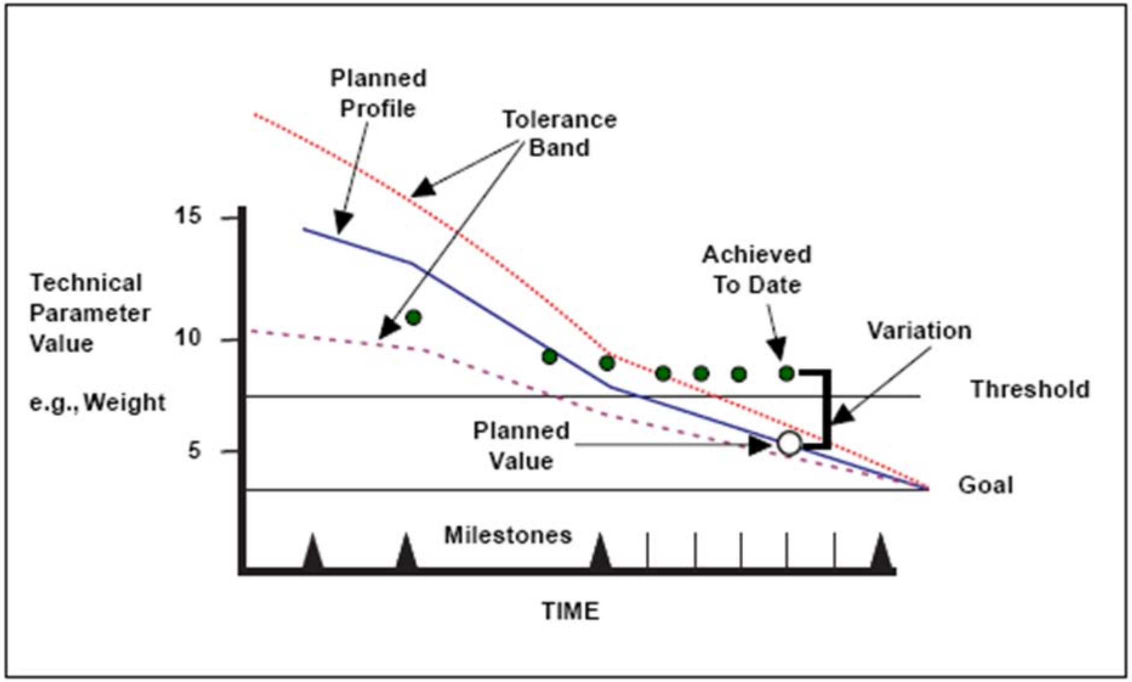
Initially the program had selected a calendar date, but in subsequent planning made the decision to have SRR be event driven, resulting in a new date for review

Revised date was set based on an acceptable level of requirements validation in accordance with the leading indicator

Had original date been used, it is likely SRR would not have been successful



How Best to Display Leading Indicators?



What information?

How much information?

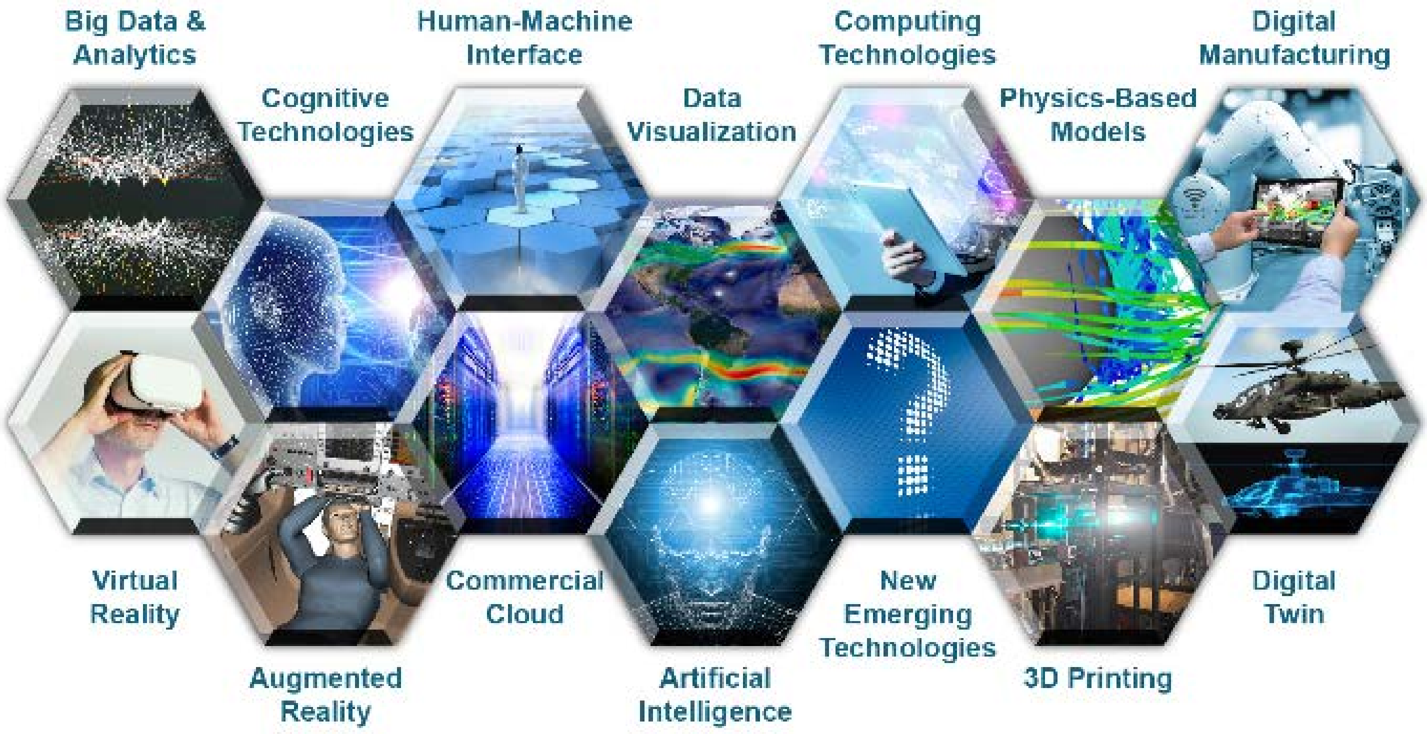
Format of information?

Interaction with information?

Given composability of measurement data, decision-makers will face increased complexity in comprehending the information, as well as need to understand the underlying assumptions and uncertainties in the constituent data elements

Leading Edge Technologies

what are the implications and opportunities for measurement of engineering performance?



Source: DoD, Digital Engineering Strategy, 2018, p12

Big Data in Digital Engineering

Digital engineering programs will be faced with dealing with these aspects of big data –

- *volume*: the magnitude of digital engineering information
- *variety*: the existence of digitized assets (e.g., pictures, drawings, etc.) that are not in themselves models
- *velocity*: rapid information flow (e.g., operational digital twins sending information back to the digital system model)
- *veracity*: uncertainty inherent in model data (e.g., artificial data from simulations, incomplete data, subjectivity in models).

Finding from Prior Research

Program managers looked at measure from perspective of,
…what decision can I make with this?

Systems Engineering experts evaluated measures from perspective of
…how useful is this measure in elevating system issues and how difficult is it to gather the data to track this measure?

<u>Open research question:</u>

How can we personalize the information displayed?

Visual Analytics in Digital Engineering

As engineering becomes model-based, the available information to draw on to generate measures of effectiveness is vast and complex.

- **Visual analytics** is fundamentally about collaboration between a human and a computer using visualization, data analytics, and human-in-the-loop interaction
- More than just tools, VA **aims to take advantage of a human's ability to discover patterns and drive inquiry to make sense of data**

- ***…it is foreseeable that decision-makers could be presented with large amounts of data that would be cognitively challenging to comprehend and find patterns that could be used to judge effectiveness of engineering on an ongoing program***
- ***knowledge and recent advancements in visual analytics may offer significant support in processing and displaying measurement data***

Interactive Dashboards

Measurement dashboards used, but largely as static display of information.

- Visual analytics and interactive technologies provide opportunity to create dynamic dashboards that enable a decision-maker to be able to interact with the data

- Provides more transparency to underlying data, enabling development of understanding and trust in the information

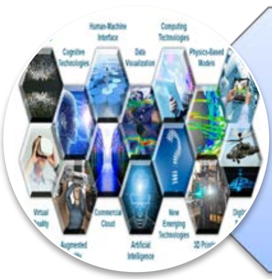
Vitello and Kalawsky (2012) state the "guiding process in visual analytics is a synergy between interactive visualization and automated analysis of the data"

Thiruvathukal et al. (2018) shows potential for using open source software repositories in the development of software metrics dashboards

Summary

Imperative for **engaging systems community**, as for prior effort

Initial step – **re-examine and augment** current set of SE leading indicators



Follow-on research to investigate **advanced indicators and applying new technologies**

Practical Software and Systems Measurement

Objective Information for Decision Makers

Adapting Systems Engineering Leading Indicators for Digital Engineering

September 17, 2019

Donna Rhodes, MIT

Adapting Systems Engineering Leading Indicators for Digital Engineering

Workshop Objectives

1. *Re-initialize a community effort on leading indicators in context of digital engineering*

2. *Gather expert insights and perspectives to inform new research on this topic*

Open question: should there be LIs for digital engineering and LIs for traditional engineering, or common indicators?

Goals of the Workshop

Identify existing leading indicators (as-is and/or useful if adapted) - published in current SE Leading Indicators Guide -perceived useful in model-centric/digital engineering

1. Share insights/experiences with novel adaptation/new measures of effectiveness of SE in model-centric (digital engineering) programs

2. Identify areas where potential new leading indicators could be beneficial to program leaders in assessing SE effectiveness in digital engineering programs

Workshop Background

- **PSM has been a co-leader** on developing prior leading indicators and publication of the guide
  - MIT, INCOSE and PSM share the copyright
- Initial activity targeted at **augmenting the existing guide** for digital engineering
- Need to **identify longer term effort and roadmap** for generating, publishing and disseminating a new guide
  - Includes usability testing of leading indicators

Intended Output

- **Prioritized list** of existing leading indicators that are candidates for being adapted
- Top 5 **proposed new leading indicators** to augment/replace existing leading indicators
- **Insights** on what information program leaders need to assess engineering effectiveness as unique to digital engineering/environments