Practical Software and Systems Measurement

Objective Information for Decision Makers

Adapting Systems Engineering Leading Indicators for Digital Engineering

September 17, 2019

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Please introduce yourself

Any initial thoughts you would like to share?

Workshop Goals

1. **Identify existing leading indicators (useful as-is and/or useful if adapted)** that are published in the current SE Leading Indicators Guide - perceived to be useful in model-centric/digital engineering programs

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

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

PRODUCTS

- **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

SE Leading Indicators

Version 2.0 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
- Facility and Equipment Availability Trends
- Defect/Error Trends
- System Affordability Trends
- Architecture Trends
- Schedule and Cost Pressure Trends

SE 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.

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

SE Leading Indicators

Version 2.0 guide

Category 1 **Category 2** **Category 3**

- **Requirements Trends**
- **System Definition Change Backlog Trend**
- **Interface Trends**
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Can we categorize these indicators based on extent of adaptation needed ?

Category 1

Category 1 Example

Some leading indicators will have minimal impact from digital engineering

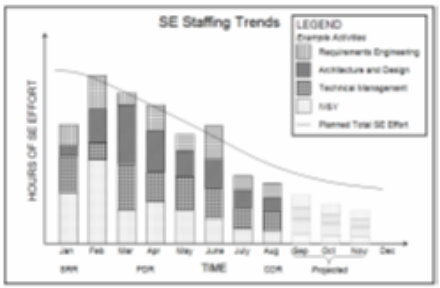
Staff and Skill Trends

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.

Systems Engineering Staff and Skill Trends



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.***
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Augmented Msmt Spec (example: HSI Considerations)

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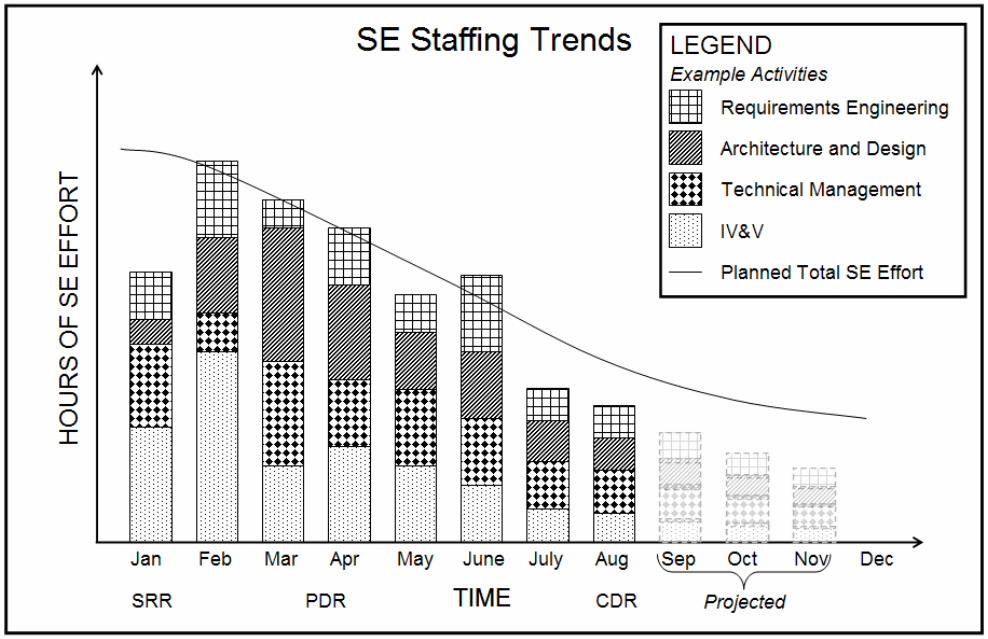

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Category 2

Category 2 Example

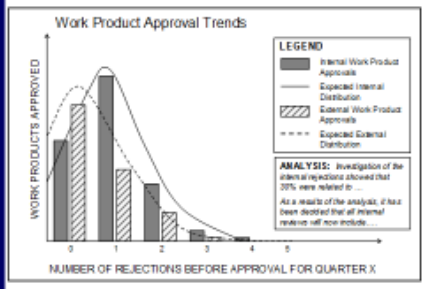
Work Product Approval Trends

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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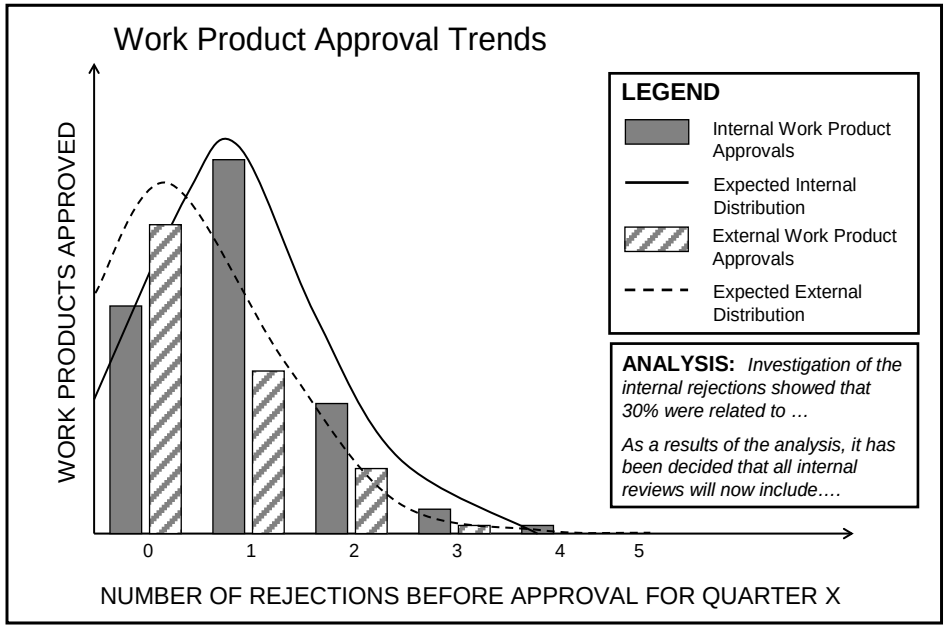


May be helpful to use a quad-chart or other graphical presentation techniques to look at performance on related work products

Category 3

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

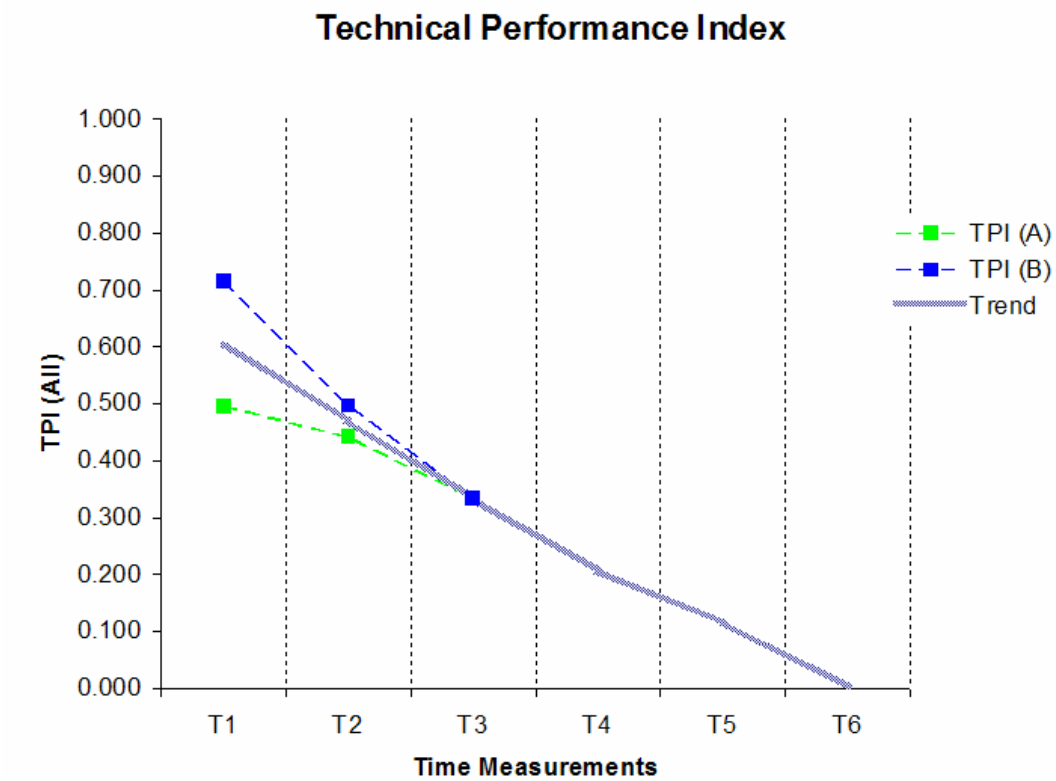
New indicators

1. Test Completeness [14]
2. Resource Volatility [13]
3. Complexity Change Trends [12]
4. **Defect and Error Trends [11]**
5. Algorithm & Scenario Trends [10]
6. **Architecture Trends [8]**
7. Concept Development [6]
8. SoS Capability Trends [6]
9. Productivity [6]
10. Baseline Mgmt [3]
11. SE Index [1]
12. Product Quality [0]
13. Team Cohesion [0]
14. End-to-end Deployment [0]

Top 5

Facilities & Equipment Availability
System Affordability Trends
Schedule and Cost Pressure

Technical Performance Measurement – *Technical Performance Index*



Index has successfully enabled discussions of programmatic technical issues, by simplifying the program details for non-technical settings while still retaining the ability to drill-down to lower tiered levels to understand problem areas with trend data

Technical Performance Index (TPI): based on the business's own defined mathematics and logic to calculate an "aggregate" trend quantifying and forecasting an overall system's performance. It provides a method to visualize aggregate system performance achievement in one graphic. For each TPI, the deviations of all the contributing TPMs are normalized from the associated thresholds.

Priority for Adaptation

Version 2.0 guide

Can we prioritize these indicators based on judgement of usefulness?

- 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
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- Systems Engineering Staffing & Skills Trends
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- Facility and Equipment Availability Trends
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- System Affordability Trends
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- Schedule and Cost Pressure Trends

Top 5 Desired LI

- What new leading indicators are needed to augment/replace existing 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]**
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Top 5

6. **Architecture Trends [8]**
7. Concept Development [6]
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12. Product Quality [0]
13. Team Cohesion [0]
14. End-to-end Deployment [0]

Facilities & Equipment Availability
System Affordability Trends
Schedule and Cost Pressure

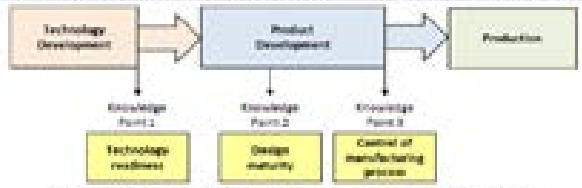
Potential future activity – use KBP approach

Knowledge-Based Practice Approach

Dr. Chris Orlowski, 2018

Systems Engineering Leading Indicators

KP	Knowledge-Based Practice [1]	Systems Engineering Leading Indicator [1]
	Demonstrate all critical technologies in a relevant environment	Technology Maturity Trends
1	Demonstrate all critical technologies in an operational environment	Technology Maturity Trends
1	Complete SRR and SFR before development start	Requirements Trends
1	Complete preliminary design review before development start	Technical Measurement Trends
2	Constrain development phase to 6 years or less	Schedule Pressure
2	Release at least 90 percent of drawings	Work Product Approval Trends
2	Test a system-level integrated prototype	Requirements Verification Trends
2	Establish a reliability growth curve	Technical Measurement Trends (ex. Reliability)
2	Identify key product characteristics	System Definition Change Backlog Trends
2	Identify critical manufacturing processes	Facility and Equipment Availability Trends
2	Conduct producibility assess. to identify mfg. risks for key technologies	System Affordability Trends
2	Complete failure modes and effects analysis	Defect/Error Trends
3	Demonstrate manufacturing process capabilities are in control	Process Compliance Trends
3	Demonstrate critical processes on a pilot production line	Defect/Error Trends
3	Test a production-representative prototype in its intended environment	Requirements Validation Trends



Cycle for Providing Users a Product with Better Capabilities [1]

Discussion

What information do program leaders need to assess systems engineering effectiveness that is unique to digital engineering/environments?

-
-
-
-
-

Key Takeaways/Recommendations

-
-
-
-

Please note on the attendance sheet if you have interest in engaging in future leading indicators activity as a reviewer and/or active collaborator

Contact info:

Donna H. Rhodes

rhodes@mit.edu

Backup Slides

Requirements Related Indicators

Requirements Trends	**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.**
System Definition Change Backlog Trend	**Change request backlog which, when excessive, could have adverse impact on the technical, cost and schedule baselines.**
Interface Trends	**Interface specification closure against plan. Lack of timely closure could pose adverse impact to system architecture, design, implementation and/or V&V any of which could pose technical, cost and schedule impact.**
Requirements Validation Trends	**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 & schedule baselines and customer satisfaction.**
Requirements Verification Trends	**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.**

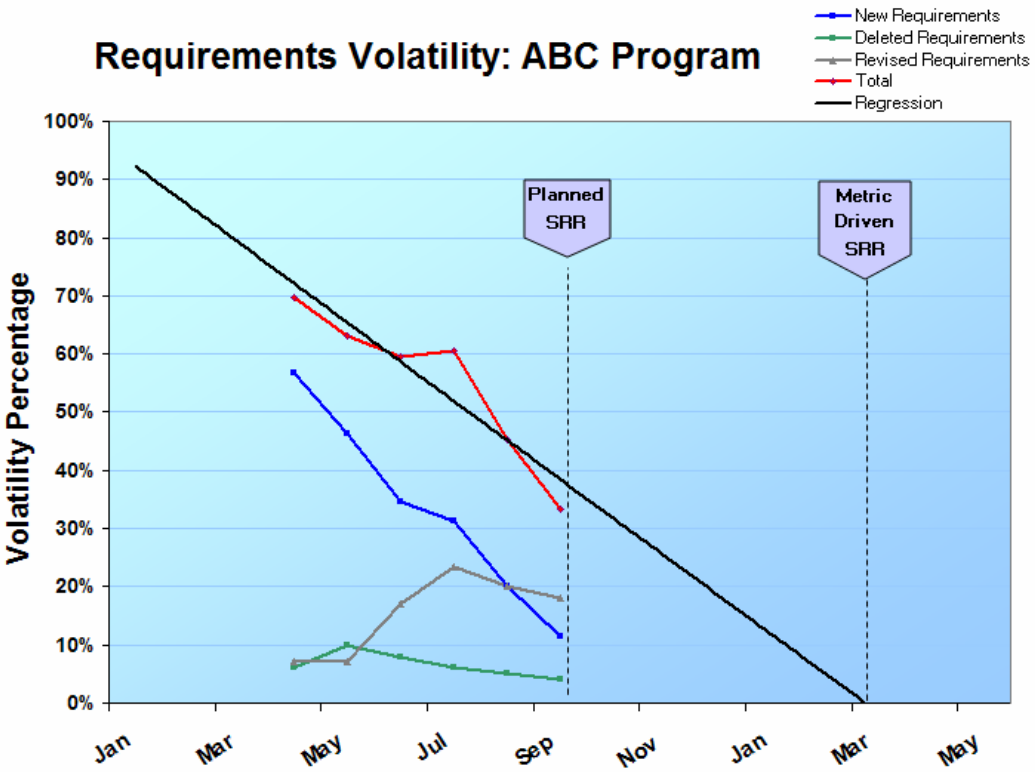
Real-world example (defense) of how leading indicators contributed to effective decisions

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

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

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

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



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Technology Maturity Trends

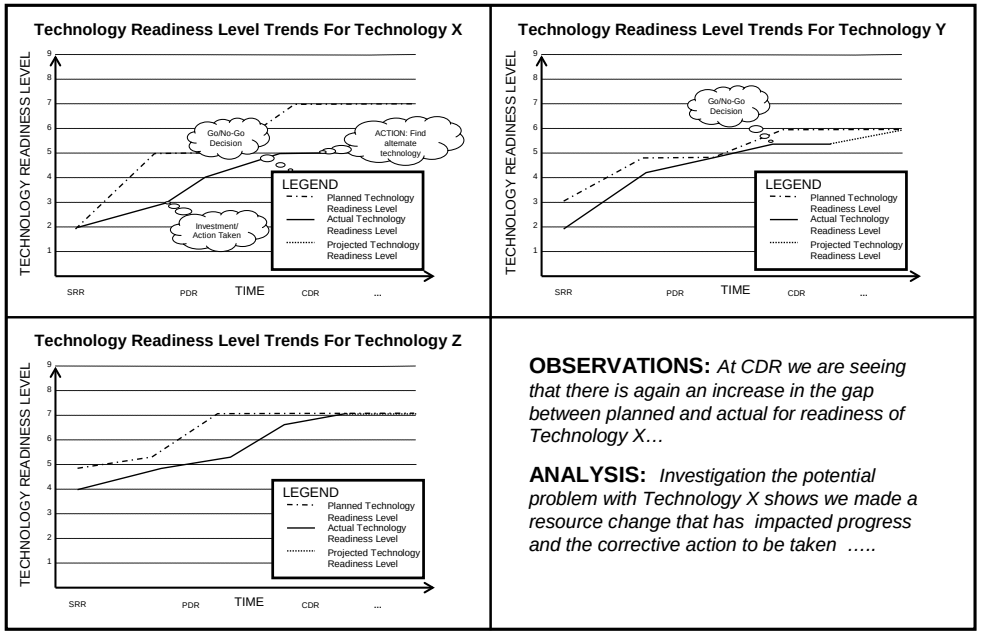
Used to evaluate the trends in technology maturity trends, including <u>readiness and obsolescence</u>, of specific technologies that are under development

May indicate that technology opportunities exist that need to be examined and may warrant product changes

May also indicate <u>when a technology is becoming obsolete</u> and may be a candidate for replacement

Gives an indication of when take action due to obsolescence risk

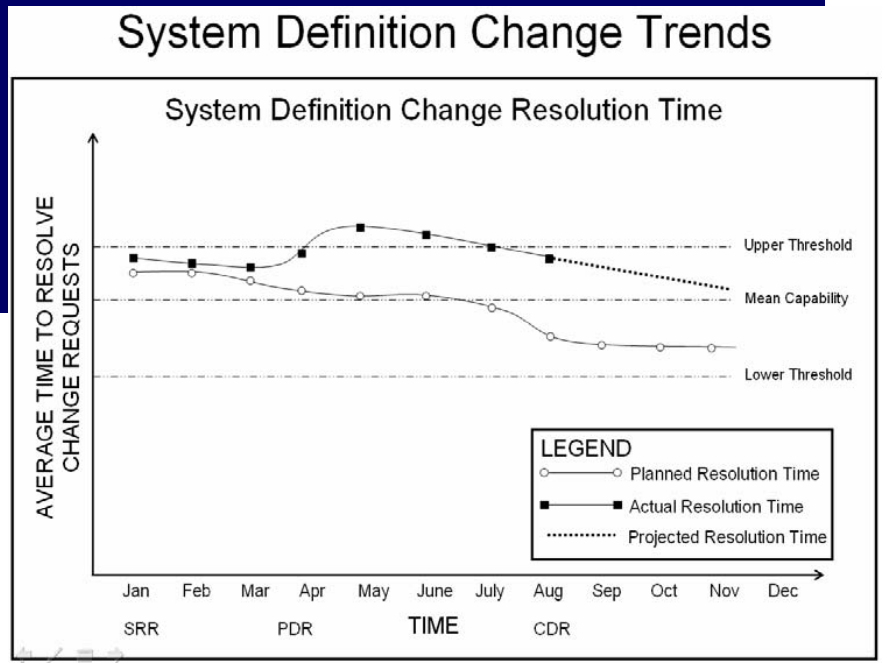
Technology Maturity Trends



System Definition Backlog Trends

Illustrates <u>average time to resolve change requests</u> versus what is planned for program or historical data. Based on historical data and nature of program, a projection is made for future; In this case, actual data depicted through Program Period 2 warrants further analysis as it is significantly over expectations (it is neither to program plan or historical-based projects) and may not be trending appropriately over time.

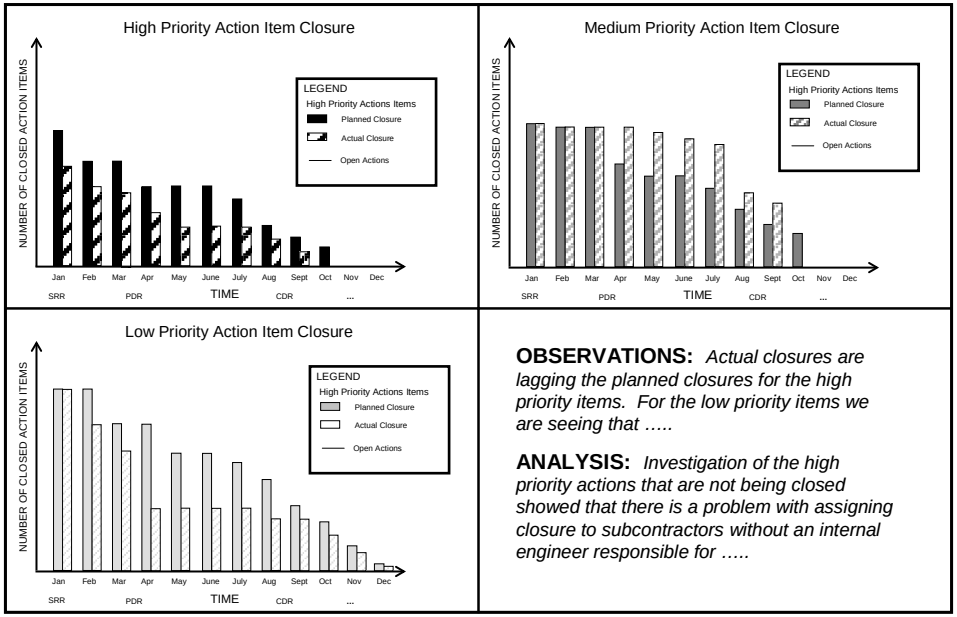
Mature organizations should be able to <u>identify lower and upper thresholds, as well as average time</u> (organization's mean capability), to resolve.



Review Action Item Closure Trends

- Review actions items may be technical or management/ communication related.
- Large deviations for planned closure may be indicative of larger, more complex tasks ahead or potentially is a sign of challenging personnel interfaces.
- In either case, <u>indicator reveals project risk in terms of rework and/or infeasible schedule</u>.
- Positive trends will provide <u>insight into readiness to move to next step/phase.</u>

Review Action Item Closure Trends



A measurement analyst would be able to make observations that would require additional detailed analysis to decide if corrective action was required, and the nature of such action.

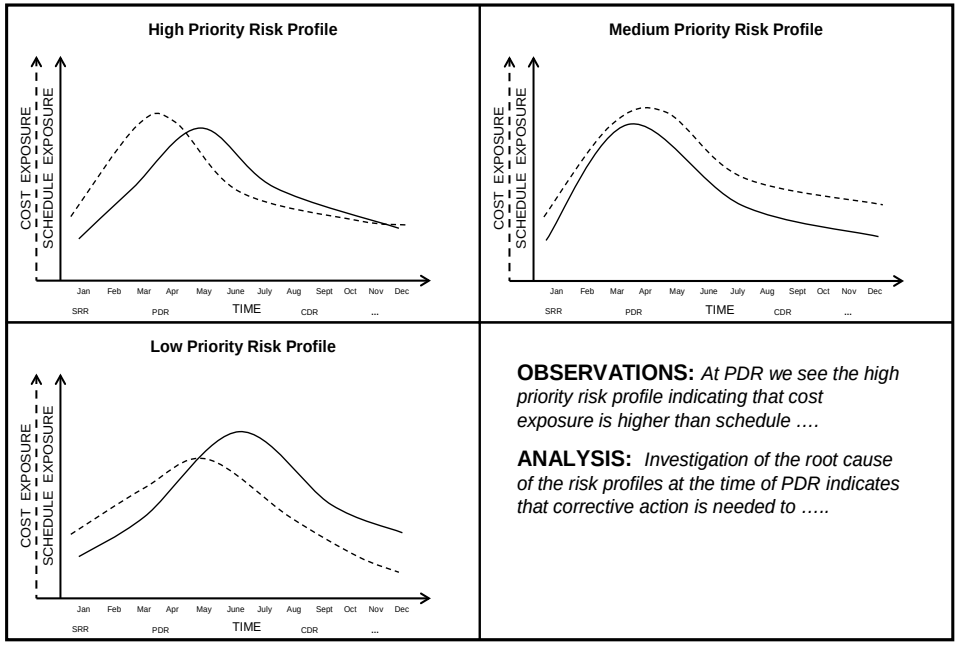
Risk Exposure Trends

Used to evaluate the risk exposure over time in terms of cost and schedule, and in context of the level of risk.

Indicates <u>whether the program is effectively managing program risks</u> as shown by predicted exposure ratings over time.

Graph illustrates risk profiles of program in regard to cost and schedule exposure over the life cycle. In this case, profiles for high, medium, and low priority risks are shown separately.

Risk Exposure Trends



If the risk exposure continues to grow or not be reduced, customer satisfaction will be negatively impacted due to resulting cost, schedule, or technical impacts

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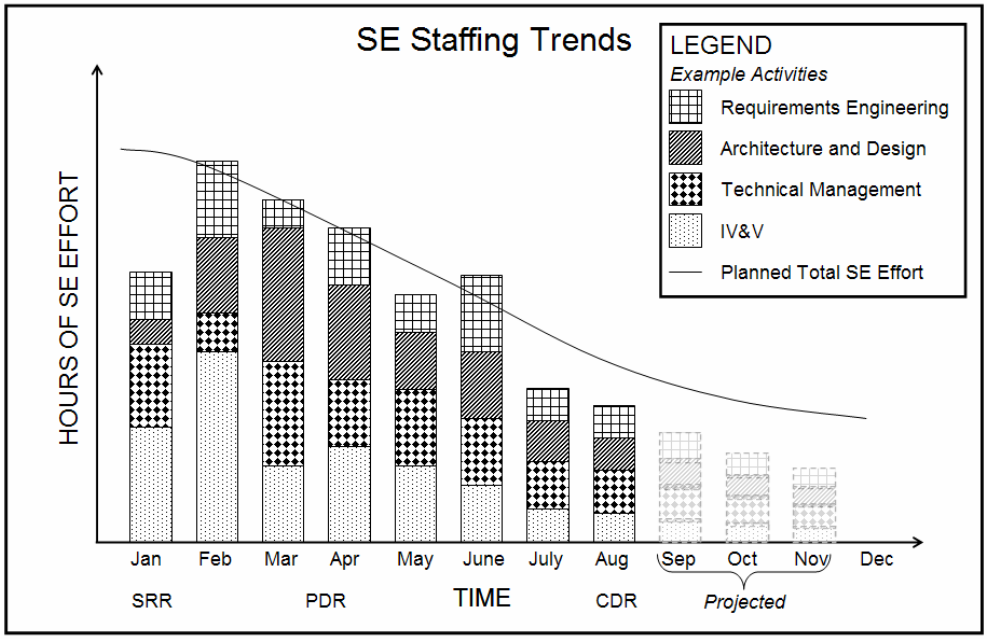

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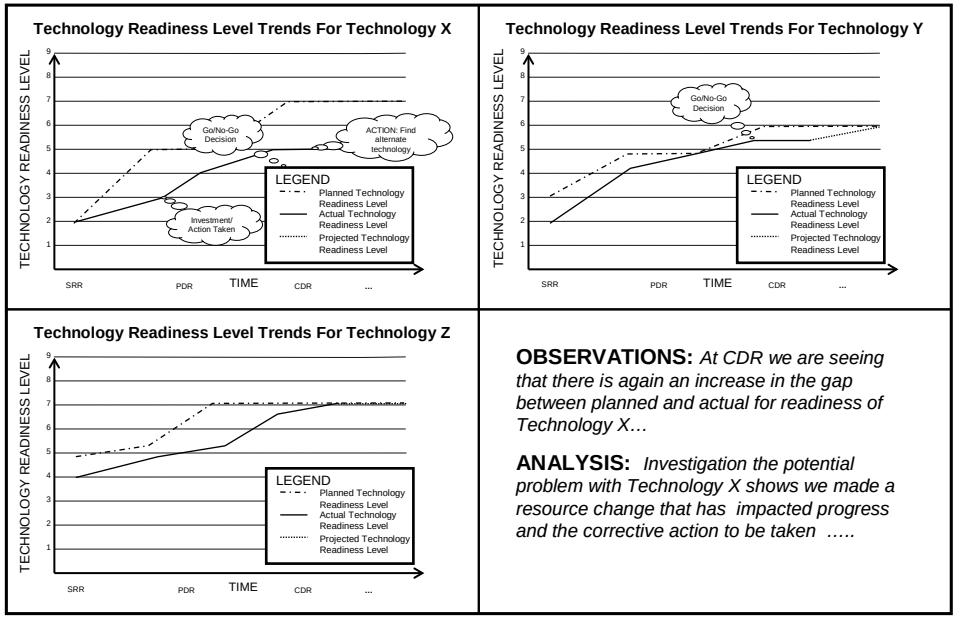

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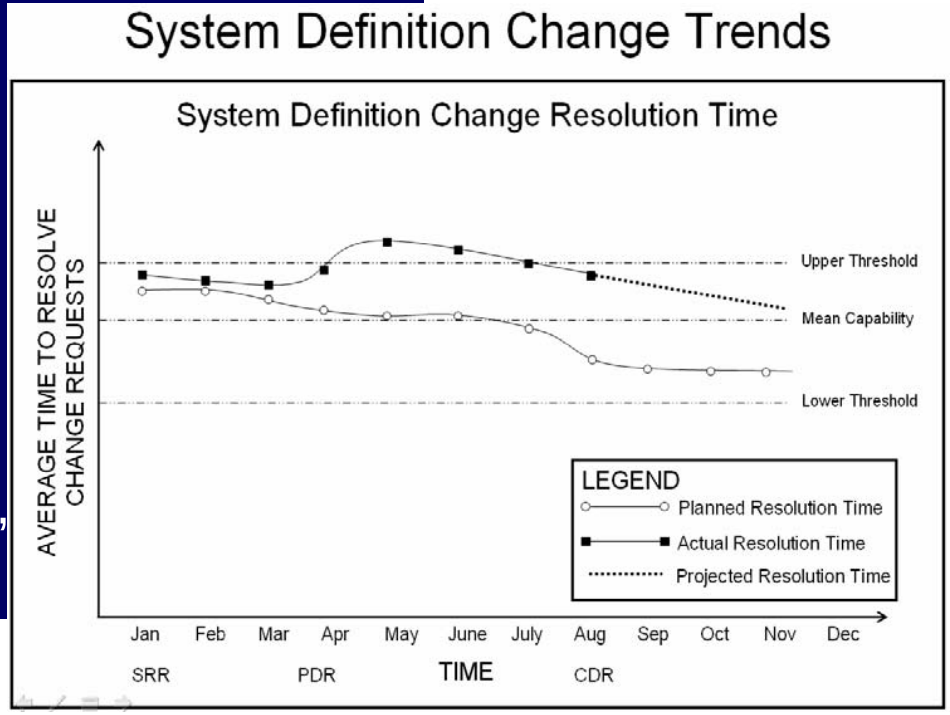
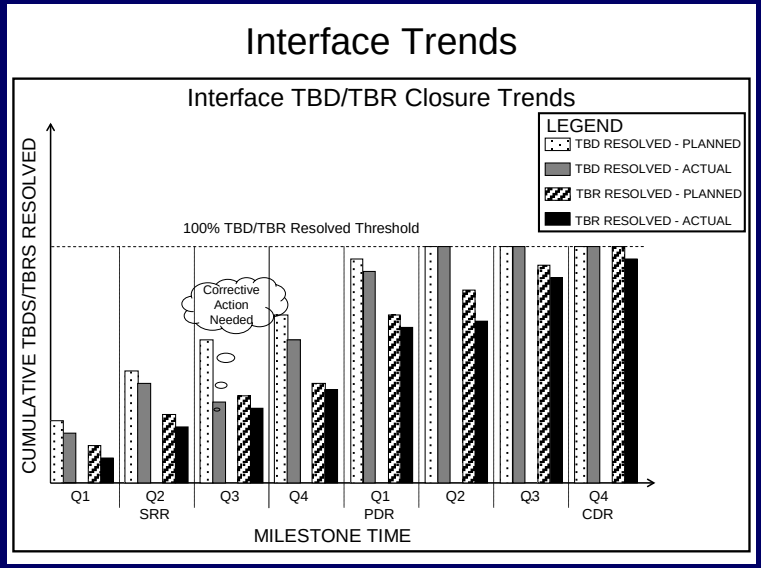


Interface Trends

Used to evaluate trends related to growth, change, completeness, and correctness of definition of interfaces.

Provides insight into rate of maturity of system definition against plan.



Assists in evaluating stability and adequacy of interfaces to understand risks to other activities towards providing required capability, n-time and within budget.

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.

Workshop Introduction Slides

Workshop introduction slides

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