Leading Indicators for Systems Engineering

Six Annual NASA Project Management Challenge

Dr. Donna H. Rhodes
Massachusetts Institute of Technology
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Topics

- Concepts and Motivation
- Leading Indicators Project
- Selected Examples
- Challenges
- Results and Next Steps

Although the leading indicators project is targeted for systems engineering, the concepts are generally applicable

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What Drives Measurement?

Directives

- Customer or corporate directives
- Prime contractor requirement
- Best practices

Competition/Cooperation

- Competitive Advantage
- Team/partner measurement practices

Internal Motivations

- Process and measurement standards
- CMMI/Process Improvement
- Need for program insight

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Measurement is Used To…

Characterize Gain understanding of processes, products, resources, and environments
Evaluate Determine status with respect to plans
Predict Support planning, prepare new proposals, and anticipate issues
Control Support decisions to implement control action
Improve Identify root causes, deficiencies, inefficiencies, and opportunities for improvement

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Measurable Aspects and Criteria

Schedule/ Progress

Resources and Cost

Growth and Stability

Product Quality

Development Performance

Enterprise Performance

Technical Maturity

Relevance

- Why do I want to collect this? Will I get result I want?

Completeness

- Have I covered all the basics?
- Left out a key parameter?

Timeliness

- Was collection and analysis accomplished in time for needed decision making and corrective action?

Elegance

- Can I collect this easily and cost effectively? Can users understand what I mean?

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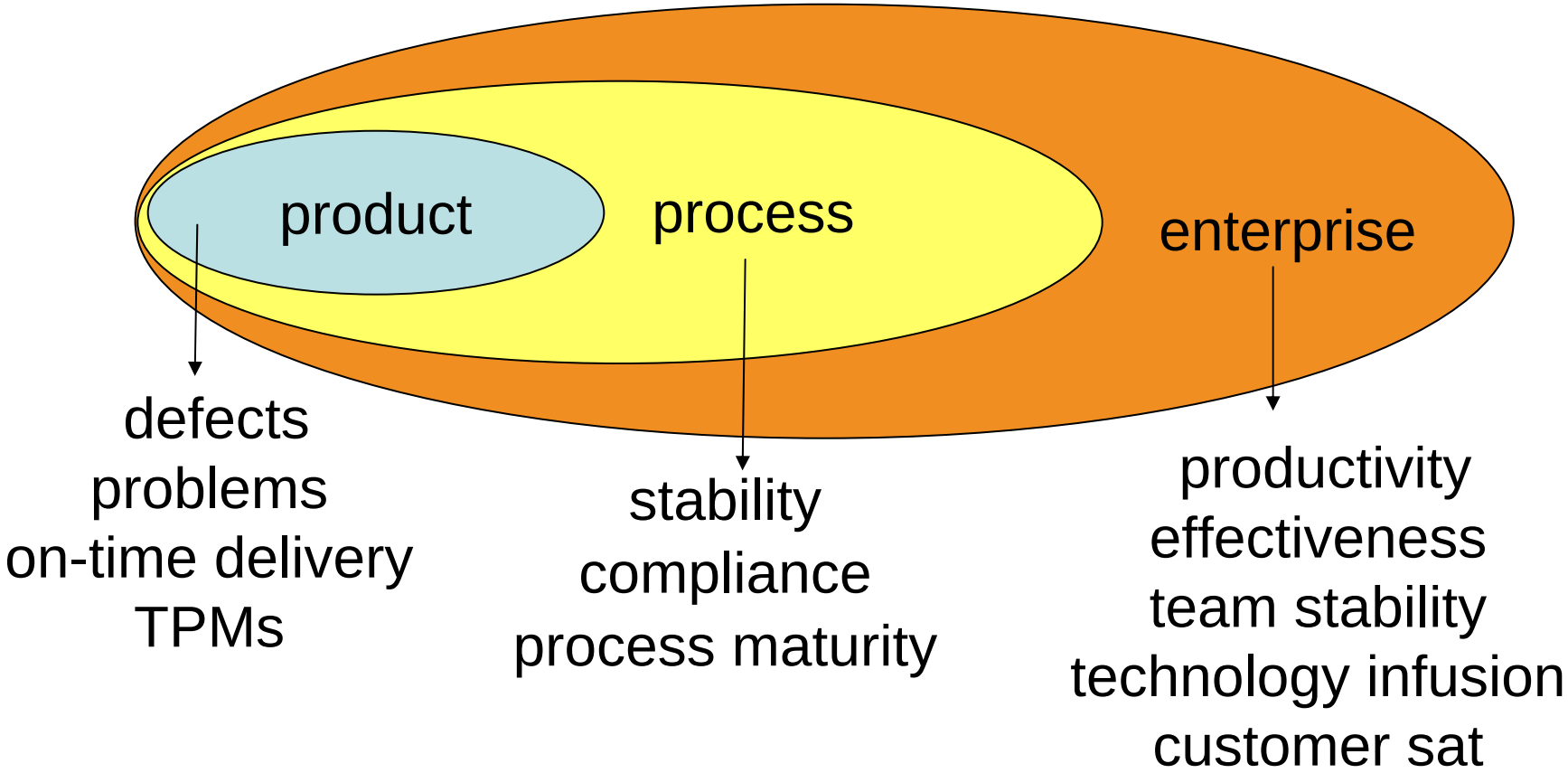
Where does measurement focus?



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Leading Indicators Project
Motivation Behind Measurement

- **Trend Detection**
- **Planning and Estimation**
- **Process and Product Improvement**
- **Progress Assessment**
- **Prediction and Control** **Where traditional SE metrics fall short**

… at both the project <u>and</u> organizational levels

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Motivation, Issues and Questions

- ***How do I know if a program is performing good systems engineering? -- Dr. Marvin Sambur, US Air Force, 2004***
- ***How can metrics that help me plan new programs also help me manage my current one?***
- ***Where can I find good practices on using and interpreting metrics – and by that I mean what real practitioners have discovered?***
- ***How can industry, government, and academia collaborate to help make traditional metrics more useful?***
  - ***Project undertaken by LAI in 2004 – co-led by academia (MIT, Rhodes) and industry (INCOSE/LM – Roedler)***
  - ***Subsequently became a joint project with INCOSE and PSM to involve wider systems community***

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LEADING INDICATORS

Our industry today is characterized by extended enterprises developing complex systems /systems of systems….

long lifecycles, constrained resources, and complexity of programs increase the importance of predicting engineering effectiveness

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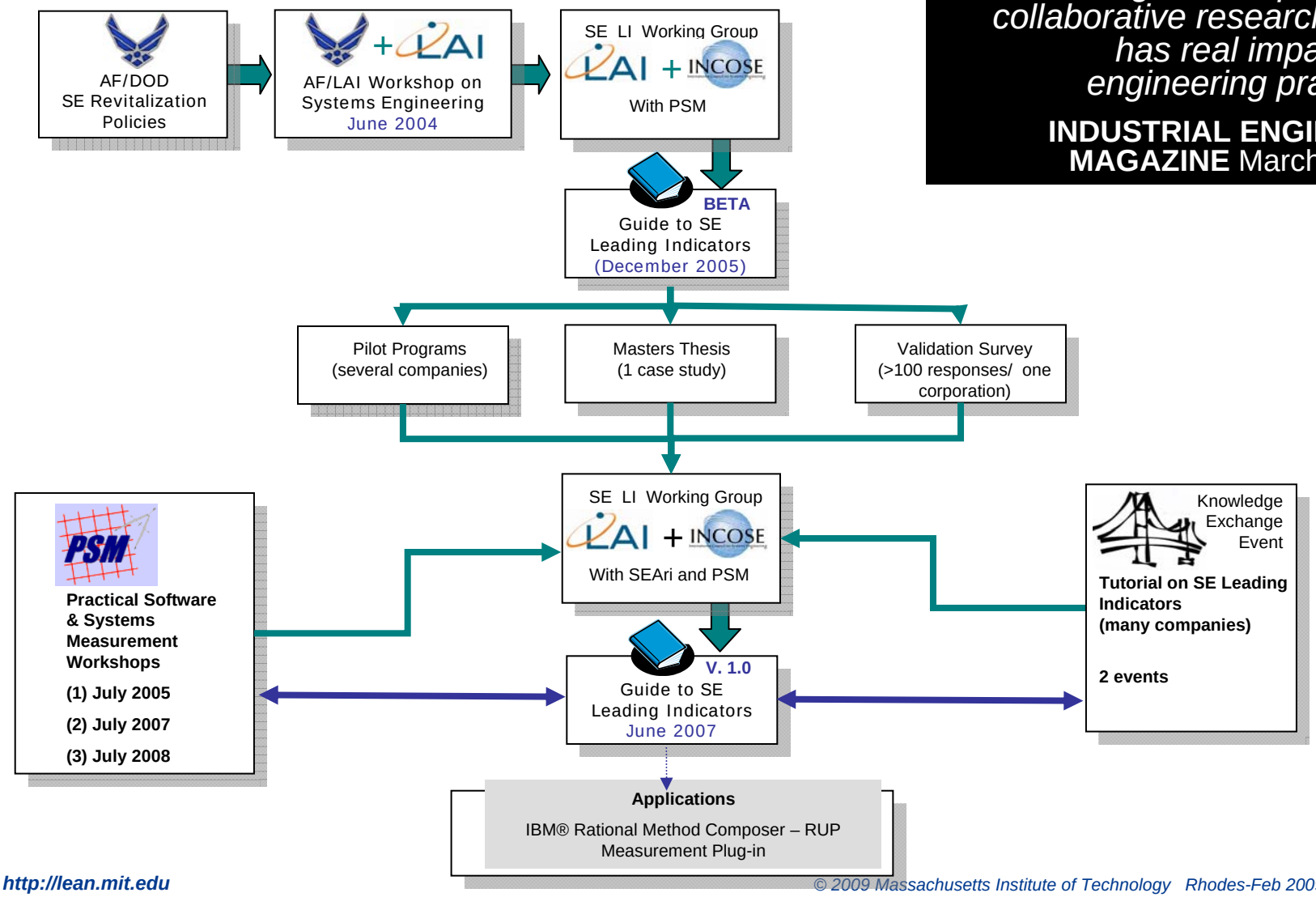
History of Project

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

INDUSTRIAL ENGINEER MAGAZINE March 2007



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What are Leading Indicators?

A leading indicator is a measure for evaluating the effectiveness of a how a specific activity is applied on a program in a manner that provides information about impacts that are likely to impact the system performance objectives.

- A leading indicator may be an individual measure, or collection of measures, that are predictive of future system performance before the performance is realized.

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How do Leading Indicators Differ from Conventional Measures?

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

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Systems Engineering Leading Indicators

Thirteen leading indicators defined by SE measurement experts

Developed by a working group sponsored by Lean Aerospace Initiative (LAI) collaboratively with INCOSE and PSM

Beta guide released December 2005; pilot programs followed

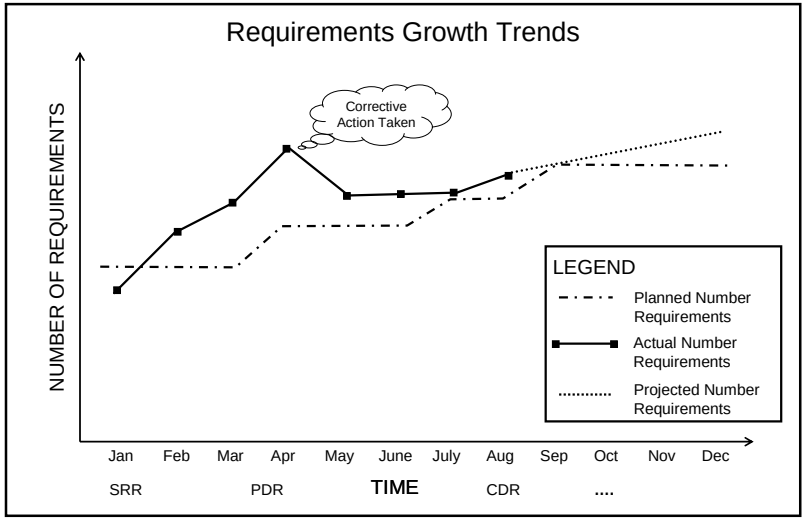
Version 1.0 released July 2007

Additional leading indicators being defined; several companies tailoring the guide for internal use

Version 2 planned for mid-2009

<u>Objective</u>: Develop a set of SE Leading Indicators to assess if program is performing SE effectively, and to enhance proactive decision making

Requirements Trends



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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

Additional leading indicators to be developed

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Fields of Information in Specification for Each Leading Indicator

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

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

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Leading Indicator Specifications

LEADING INDICATOR X	
Measurable Concept and Leading Insight	
Measurable Concept	**Defines specifically what is measurable – typically in the form of a question that can be answered that relates to the programmatic or technical performance**
Leading Insight	**Specifies what specific insights that the leading indicator may provide in context of the measurable concept -- typically a list of several or more**

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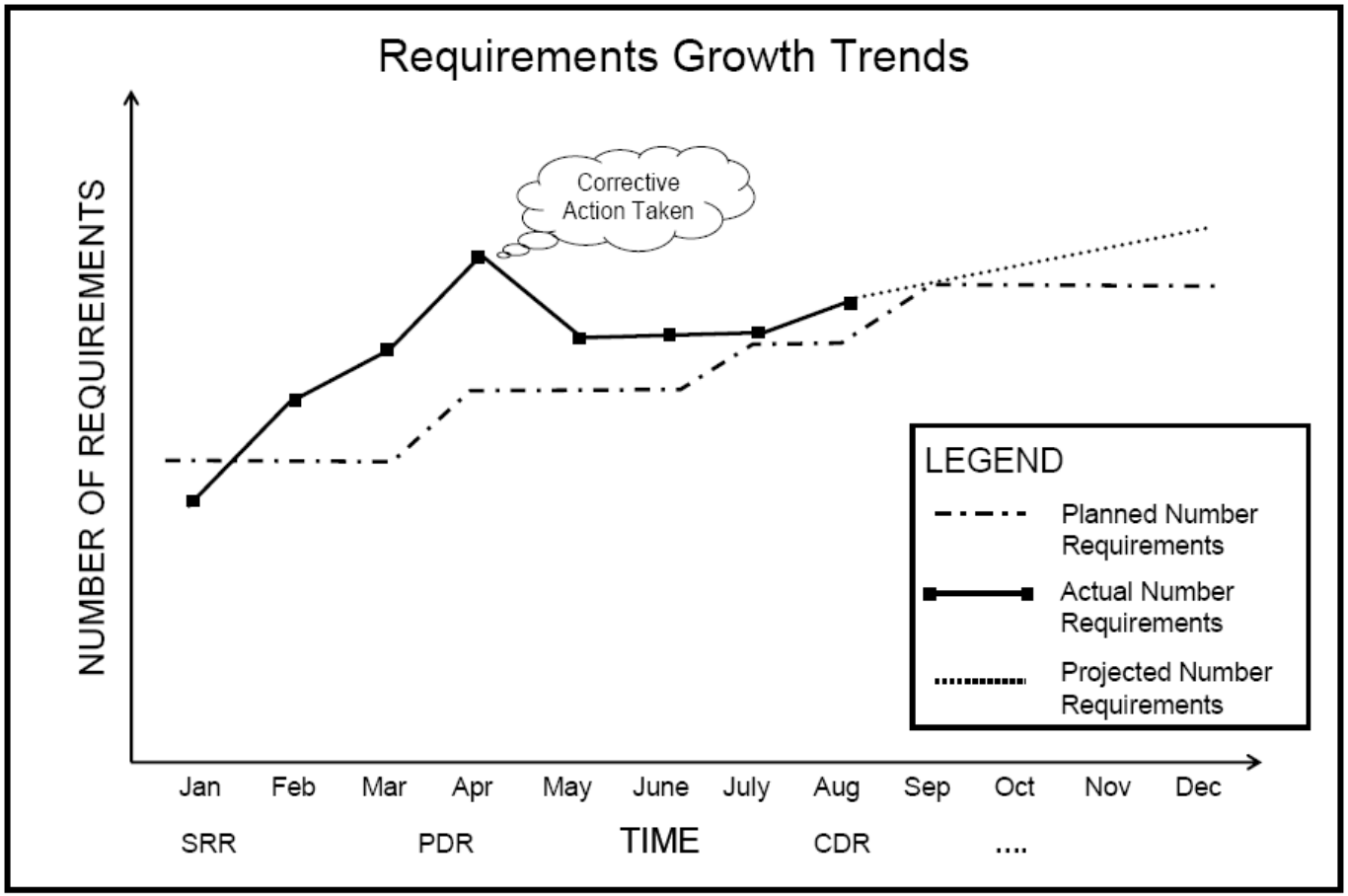
Notional Example of Requirements Trends



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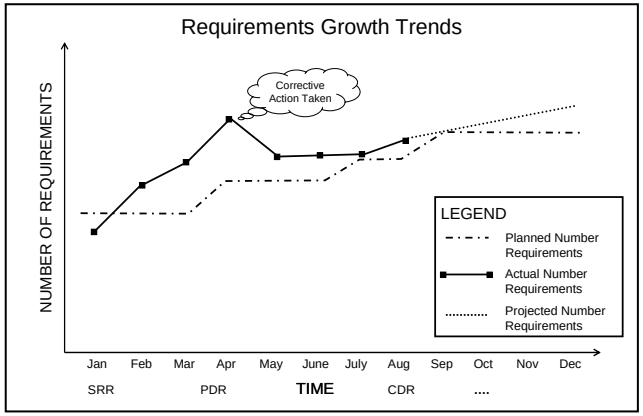
Example Indicator Requirements Trends

Requirements Trends



Evaluate trends in the growth, change, completeness and correctness of definition of system requirements.

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

Characterizes stability and completeness of system requirements which may impact design

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

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Possible Pitfalls
Example: Requirements Trends

Pitfalls in Implementing

- Sampling: how often do requirements really change?
- Relevance: requirements may not be an adequate metric early on in the life cycle
- Stability: requirements baseline may change over time

Pitfalls in Interpreting

- Granularity: different level of detail throughout system hierarchy
- Quality of work: no indication of workmanship

Misuse

- Requirements resolution may not be an indicator of progress
- TBDs/TBRs are not entirely within contractor's control

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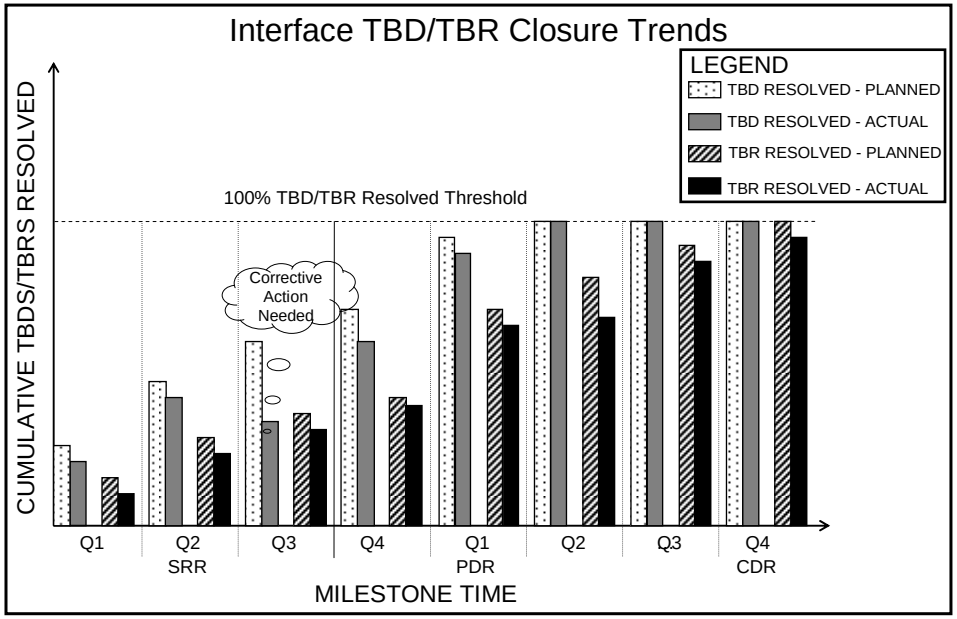
Interface Trends

Notional example



This indicator is used to evaluate the trends related to growth, change, completeness, and correctness of the definition of system interfaces. It provides insight into the rate of maturity of the system definition against the plan. It also assists in helping to evaluate the stability and adequacy of the interfaces to understand the risks to other activities towards providing required capability, on-time and within budget. 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.

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Leading Indicator Specifications

INTERFACE TRENDS	
Information Need Description	
Information Need	Evaluate the stability and adequacy of the interfaces 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 interfaces.
Information Category	Product size and stability – Functional Size and Stability Also may relate to Product Quality and Process performance (relative to effectiveness and efficiency of validation)

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INTERFACE TRENDS

Measurable Concept and Leading Insight	
Measurable Concept	Is the SE effort driving towards correctness and completeness (i.e., approved) of the definition and design of interfaces?
Leading Insight	Indicates whether the system definition is maturing as expected. Unfavorable trends indicate high risk during design, implementation and/or integration. Indicates risks of change to and quality of architecture, design, implementation, verification, and validation, as well as schedule and cost shortfalls. Greater interface growth, changes, or impacts than planned or lower closure rate of TBDs/TBRs than planned indicate risks to the system definition and flow-down.

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LEAN ADVANCEMENT INITIATIVE ™

INTERFACE TRENDS

Indicator Specification	
Decision Criteria	Investigate and, potentially, take corrective action when the interfaces are faulty and incomplete, interfaces change impact, or defect density/distribution exceeds established thresholds *<fill in organization specific threshold>*
Indicator Interpretation	Used to understand impact on system definition, design, and system integration. Analyze this indicator for process and system definition performance and progress, and impact to architecture, design, implementation, verification, and validation, as well as schedule and cost shortfalls. Unfavorable trends indicate high risk during design, implementation and/or integration. Greater interface growth, changes, or impacts than planned or lower closure rate of TBDs/TBRs than planned indicate risks to the system definition and flow-down.

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Leading Indicators
Mapped to Life Cycle Phases

TABLE 1. SYSTEMS ENGINEERING LEADING INDICATORS OVERVIEW						
Leading Indicator	**Insight Provided**	**P1**	**P2**	**P3**	**P4**	**P5**
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	Changes requests and backlog which, if 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.	•	•	•	•	•

see document for details

Access guidance document at
http://lean.mit.edu or http://www.incose.org

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Challenges

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Measurement: Art or Science

Methods and algorithms for computing measures make it more of a "science" …

Leading indictors involve both art and science

Interpretation of measurement data requires subjective judgments …more of an "art"

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Top Five Challenges for Leading Indicators Implementation

1. Validation of leading indicators is essential but difficult to get companies to share this
2. Due to similarity to classical metrics, leading indicators may be dismissed as 'already doing this'
3. Finding effective ways to present the information in a concise and graphical form to aid effective decisions
4. Interpretation of leading indicators is subjective and so must be carefully developed with highly knowledgeable staff
5. Finding appropriate ways to aggregate leading indictors, and to know when this should not be done

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Challenges of Interpretation

- **When interpreting leading indicators and metrics, supporting information and facts are needed** ***(rarely is this done adequately!)***

- **Never interpret on the graph or bar chart alone!** ***(too often, we do!)***

- **Interpretation must be done by involved senior level people – not delegated to an analyst** ***(too often, it is delegated!)***

- **Never assume the supporting information statys a constant**

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Challenges of Interpretation
PIZZA METRIC

Leading Indicator: Number of pizza boxes in the lab per people working in lab

- *20 empty boxes on found on Monday morning for a lab with team of 5 people but 10 boxes is typical…*

Interpretation??

- Team celebrating a success
- Project behind – team worked all weekend
- Take your child to work day on Friday
- Pizza offered 2 for 1 deal that week

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Top Three Challenges for Evolving the Leading Indicators

1. Data collection takes time and we lack any centralized repository to build a core history
2. Leading indicators require trend data and when an indicator is first introduced there is historical info on which to base trends
3. Need "next generation" leading indicators (concept phase and architecting are two key areas of interest) – but these are much more difficult define

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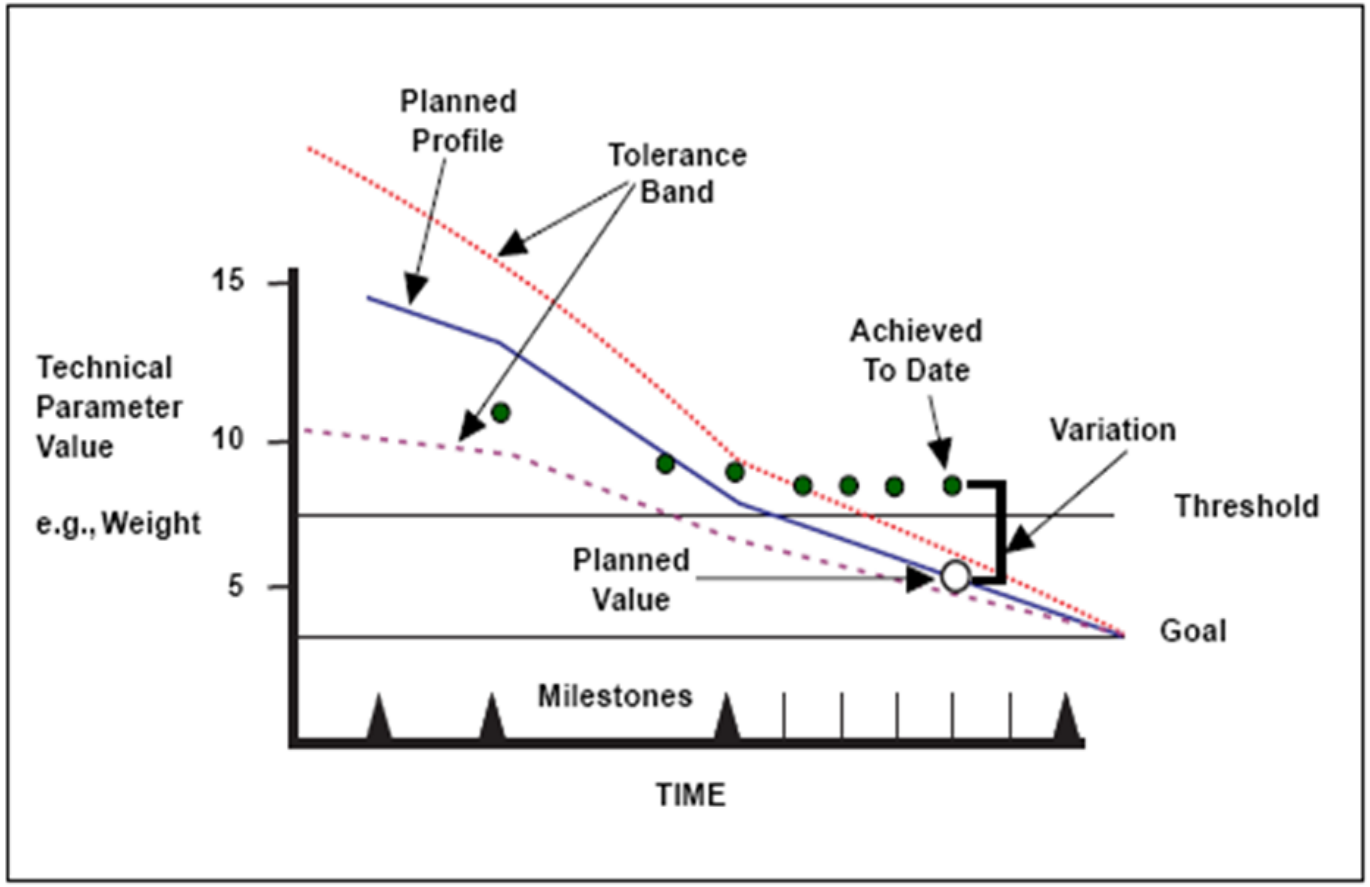
How Best to Present Leading Indicators Information?



Also difficult to get organizations to share good examples as formats often viewed as unique to company and competitive information

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RESULTS and NEXT STEPS

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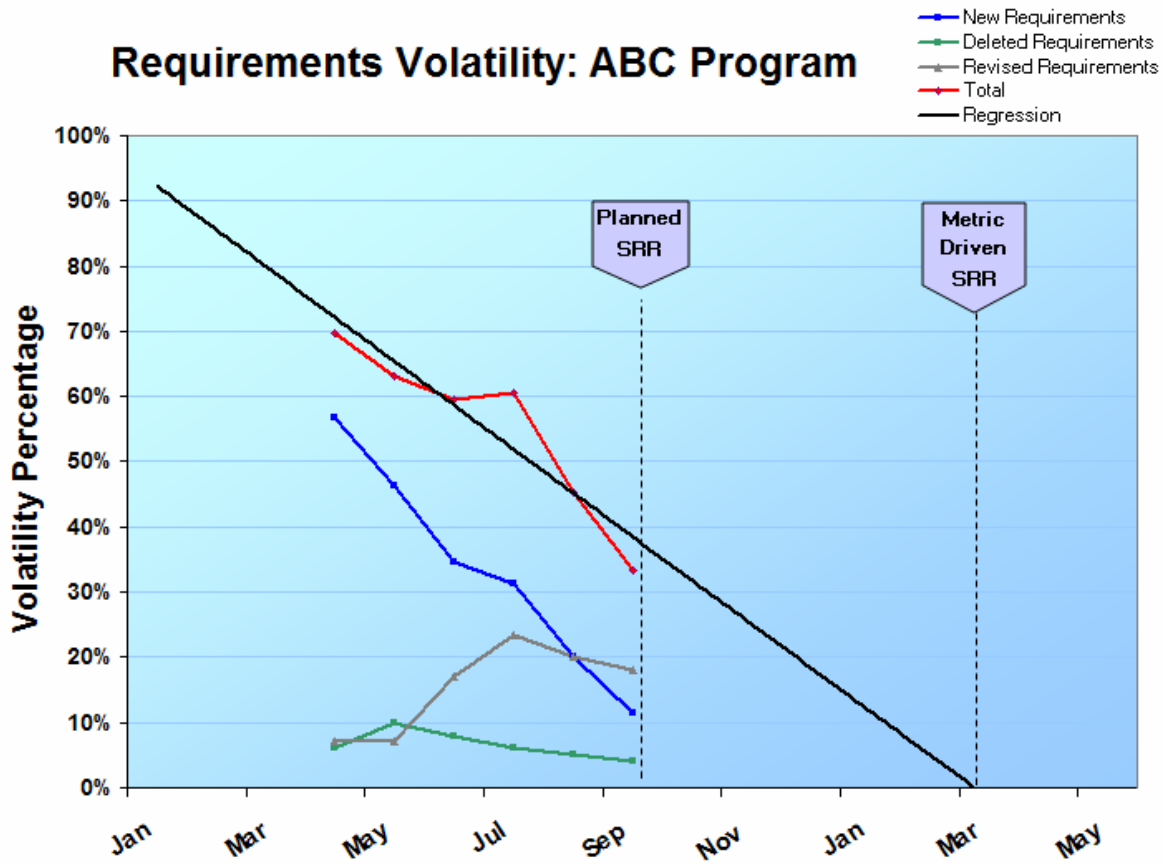
What is an example of how leading indicators have contributed to effective systems engineering on a program?

By monitoring the 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 the 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 that the SRR would not have been successful



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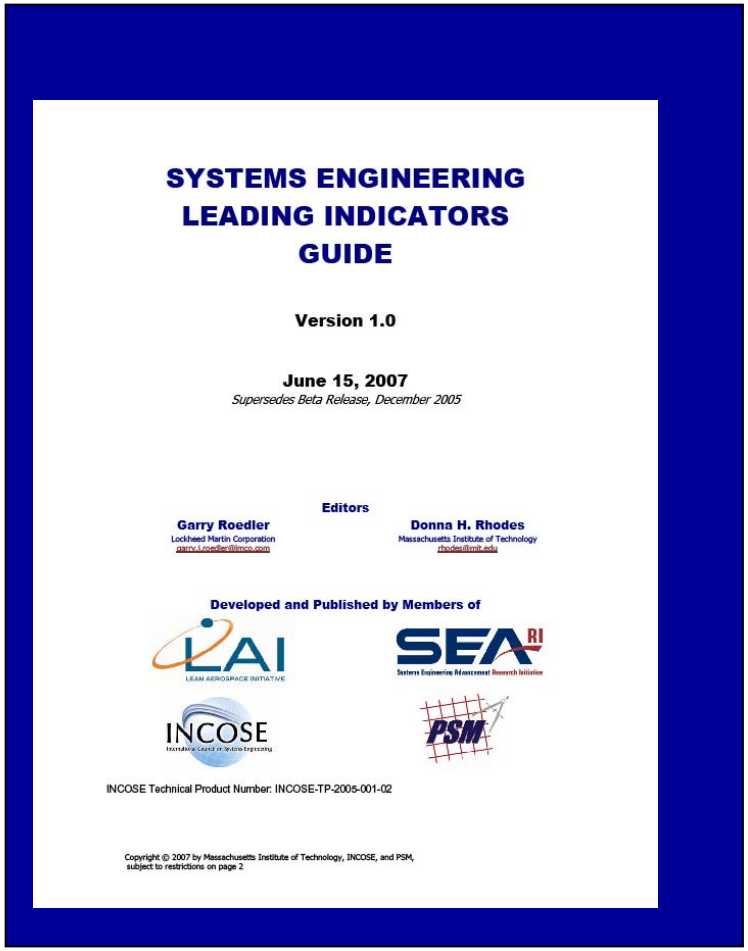
Systems Engineering Leading Indicators Guide



SYSTEMS ENGINEERING LEADING INDICATORS GUIDE

Version 1.0

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Editors

Garry Roedler
Lockheed Martin Corporation
garry.j.roedler@lmco.com

Donna H. Rhodes
Massachusetts Institute of Technology
rhodes@mit.edu

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- Knowledge Exchange Events and several industry workshops to validate and extend
- Several companies tailoring guide for internal use
- New MIT research extending to human systems integration
- In IBM Rational RUP
- Journal article in 2008
- Version 2.0 underway

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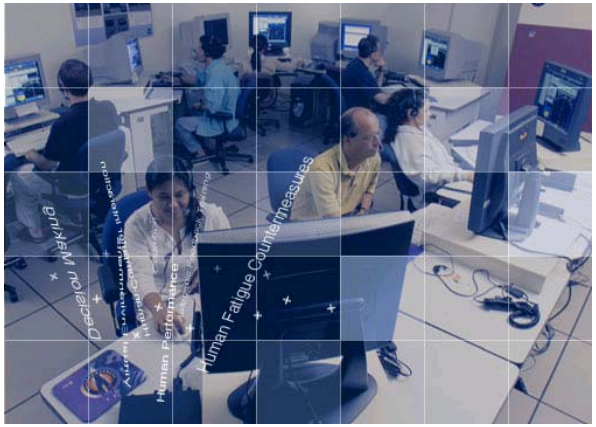
Industry Survey on Usefulness of SE Leading Indicators (100+ experts)

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*

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.

Future Direction
SE Leading Indicators Research



- **Follow-on studies of long term impact of leading indicator triggered program actions**
- **MIT research to extend leading indicators to Human Systems Integration**
- **INCOSE Measurement Working Group – validation and updates**
- **Version 2.0 of Guide to be released mid- 2009**

Rhodes, D.H., Valerdi, R. and Roedler, G.J., "Systems Engineering Leading Indicators for Assessing Program and Technical Effectiveness," *Systems Engineering*, Vol. , No. , 2009, Early View Online

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