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Framework for Implementing Systems Engineering Measures at Technical Reviews and Audits

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Increased Complexity in Today's Systems

- Changing environment and threats
- More emphasis on multi-mission capability, adaptability and resiliency
- Results in increased complexity in functional architecture and resulting physical solution
- Complex interfaces with multiple components
- Increased software and electronics footprint
- Demand for effective systems engineering

Systems engineers solve challenging, complex problems

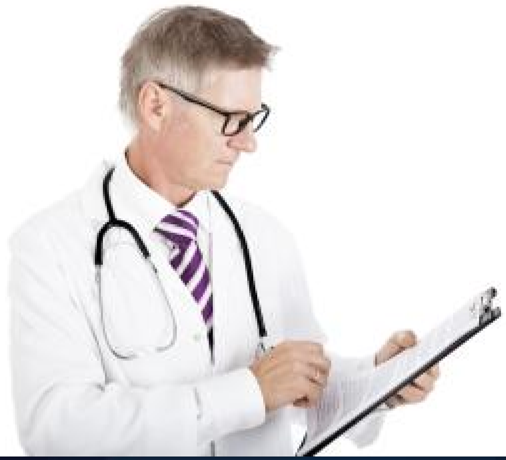
Is There a Doctor in the House?

Patient Diagnostics

- Blood Pressure
- Temperature
- Weight
- Other MD vitals

Program Diagnostics

- TPMs
- Risk Exposure
- Requirements
- Other SE vitals



Systems Engineering & Cybernetics

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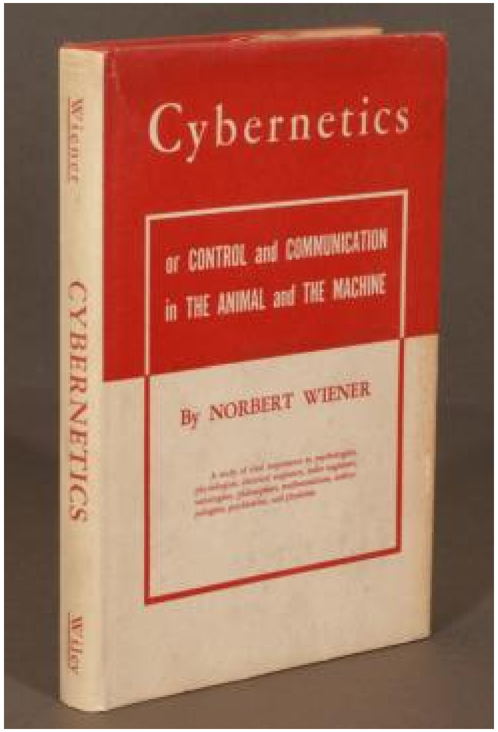
- Systems engineering emerged to address complexity and change
- Systems engineering roots can be traced to cybernetics
- Norbert Wiener authored Cybernetics in 1947 [1]
- Central to cybernetics theory is the concept of **feedback and control**
- Technical management activities required to measure and control performance are critical to ensuring systems engineering effectiveness [2]

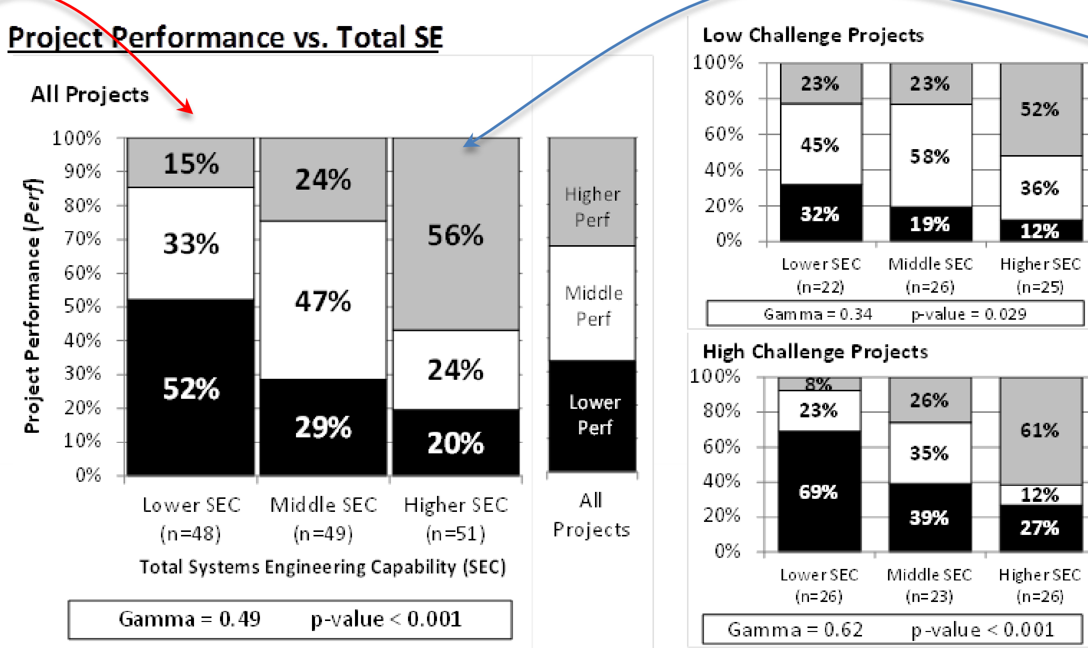


Cybernetics is defined by Webster's dictionary as "the science of communication and control theory that is concerned especially with the comparative study of automatic control systems (as the nervous system and brain and mechanical-electrical communication systems)" [3]

Systems Engineering Effectiveness [4]

- SEI & NDIA surveyed 148 development projects and found clear and significant relationships between systems engineering best practices and performance on those projects
- Projects that contained high level of systems engineering best practices performed much better than projects with low SE capability

For the projects that did the least SE, only 15% delivered the best project performance.



For the projects that did the most SE, 56% delivered the best project performance

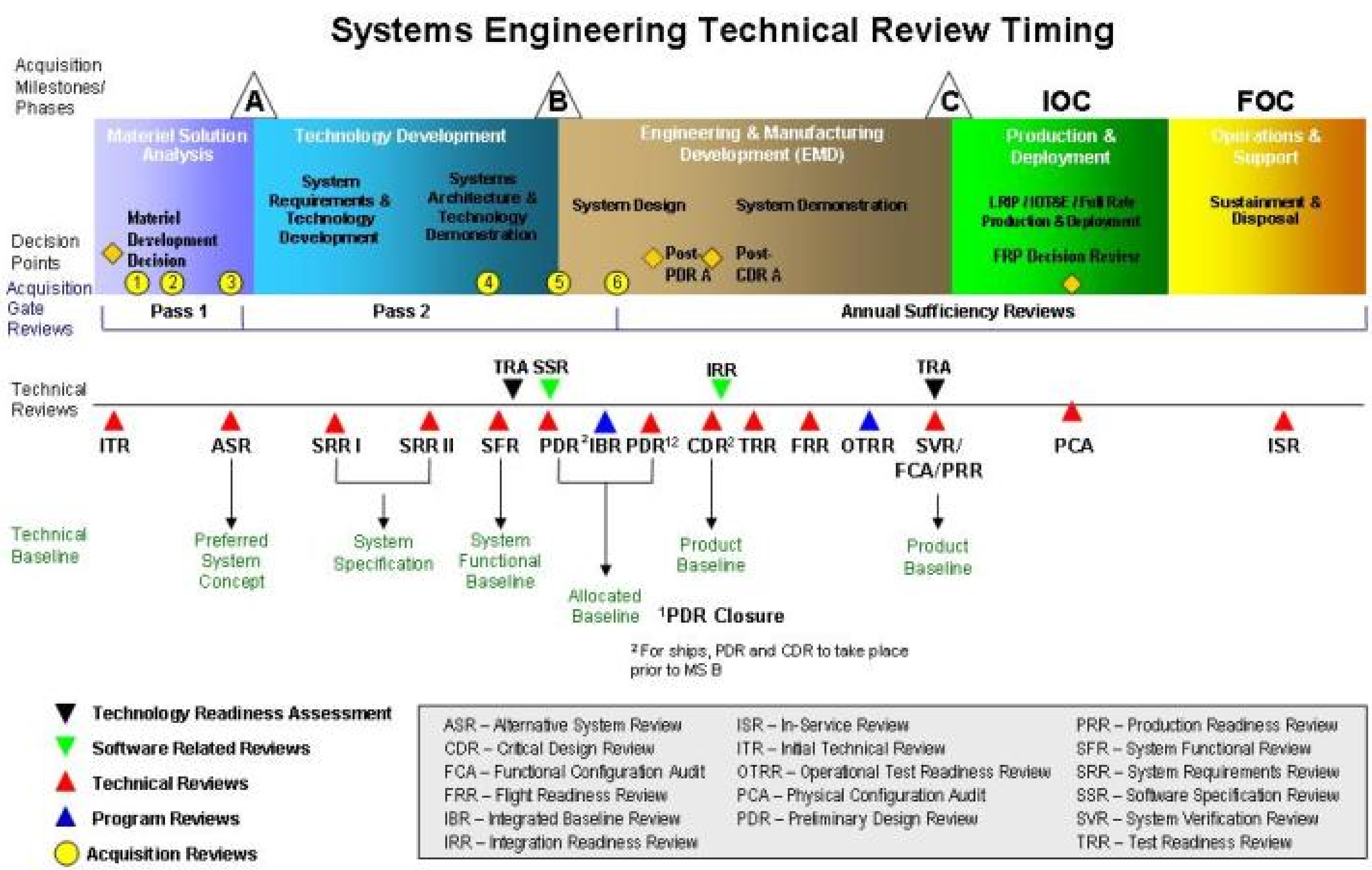
Systems Engineering Life Cycle [5]

<table>
<tr><th>Life Cycle Stages</th><th>Purpose</th><th>Decision Gates</th></tr>
<tr><td>Concept</td><td>Identify stakeholders needs
Explore concepts
Propose viable solutions</td><td rowspan="6">Decision Options:
- Execute next stage
- Continue this stage
- Go to preceding stage
- Hold project activity
- Terminate project</td></tr>
<tr><td>Development</td><td>Refine system requirements
Create solution description
Build system
Verify and validate system</td></tr>
<tr><td>Production</td><td>Produce systems
Inspect and test [verify</td></tr>
<tr><td>Utilization</td><td>Operate system to satisfy user’s needs</td></tr>
<tr><td>Support</td><td>Provide sustained system capability</td></tr>
<tr><td>Retirement</td><td>Store, archive, or dispose of the system</td></tr>
</table>

Technical Reviews and Audits [6]

Review or Audit	Description
Alternative Systems Review (ASR)	Recommendation that the preferred materiel solution can affordably meet user needs with acceptable risk. System parameters defined; balanced with cost, schedule, and risk.
System Requirements Review (SRR)	Recommendation to proceed into development with acceptable risk. Level of understanding of top-level system requirements is adequate to support further requirements analysis and design activities.
System Functional Review (SFR)	Recommendation that functional baseline fully satisfies performance requirements and to begin preliminary design with acceptable risk. Functional baseline established and under formal configuration control.
Preliminary Design Review (PDR)	Recommendation that allocated baseline fully satisfies user requirements and developer ready to begin detailed design with acceptable risk. TPM data and analyses are assessed and typically 15% of production drawings have been released by PDR
Critical Design Review (CDR)	Recommendation to start fabricating, integrating, and testing test articles with acceptable risk. Product design is stable. Initial product baseline established. all configuration items (CIs) are evaluated. As another rule of thumb, the design is approximately 80 - 85% complete by this review
System Verification Review (SVR) (i.e. Functional Configuration Audit (FCA))	Recommendation that the system as tested has been verified (i.e., product baseline is compliant with the functional baseline) and is ready for validation (operational assessment) with acceptable risk.
Production Readiness Review (PRR)	Recommendation that production processes are mature enough to begin limited production with acceptable risk.
Physical Configuration Audit (PCA)	Recommendation to start full-rate production and/or full deployment with acceptable risk.

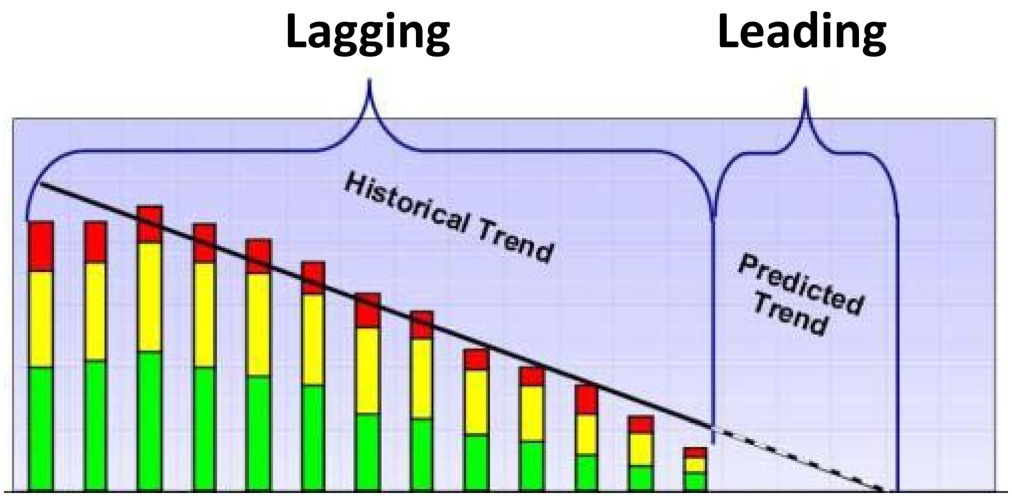
Example Technical Review Timeline [7]



Program Initiation at Milestone A

Systems Engineering Measurement [8]

- Process to collect, analyze, and report data relating to products developed
- Measured results support decision management across the system life cycle
- Provides insight into the health of the respective measured activities



"Are we on track to meet CDR?"
"Will we achieve the desired reliability performance by FCA?"
"Have we matured the detail design properly to support PRR?"

Leading Indicators Defined [9]

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INCOSE's Systems Engineering Leading Indicators Guide Version 2.0 defines SE leading indicators as:

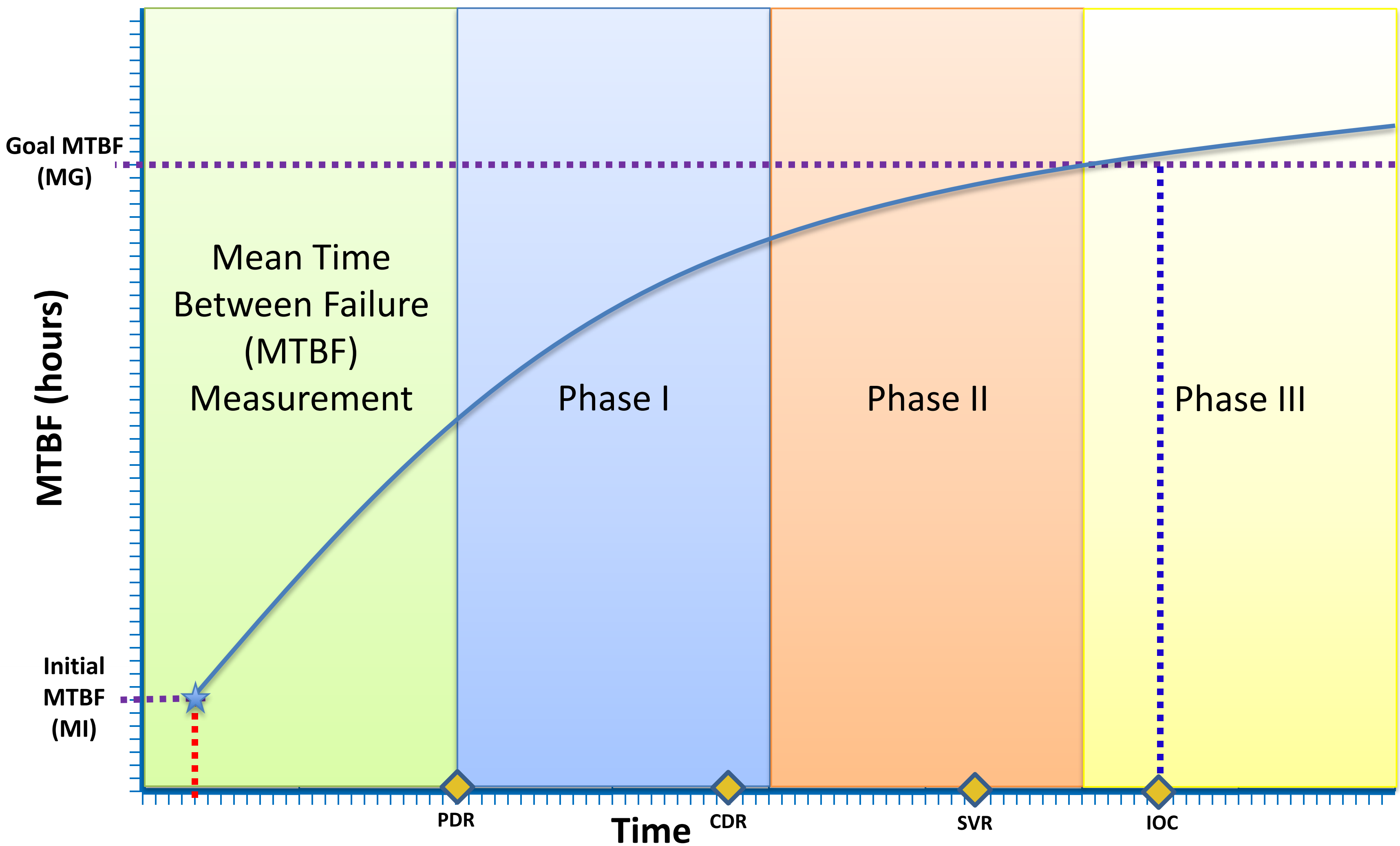
- A measure for evaluating the effectiveness of how a specific activity is applied on a project in a manner that provides information about impacts that are likely to affect the system performance objectives

- May be an individual measure, or collection of measures and associated analysis that are ***predictive*** of future systems engineering performance before the system is fully realized.

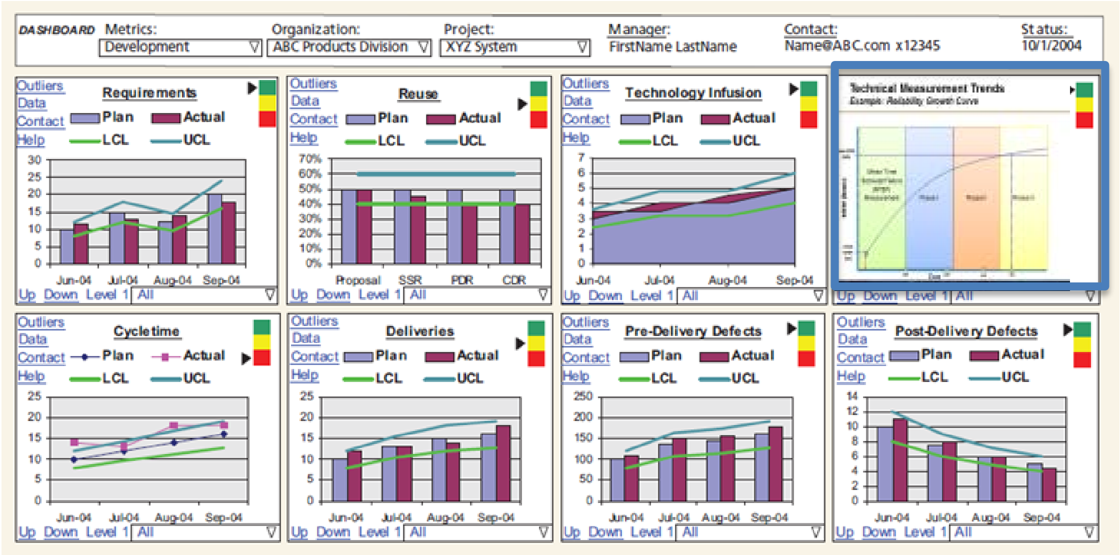
- Systems engineering performance itself could be an indicator of future project execution and system performance (see SEI/NDIA's The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey dated November 2012 – Special Report CMU/SEI-2012-SR-011)

Technical Measurement Trends

Example: Reliability Growth Curve



Technical Review Dashboard [10]



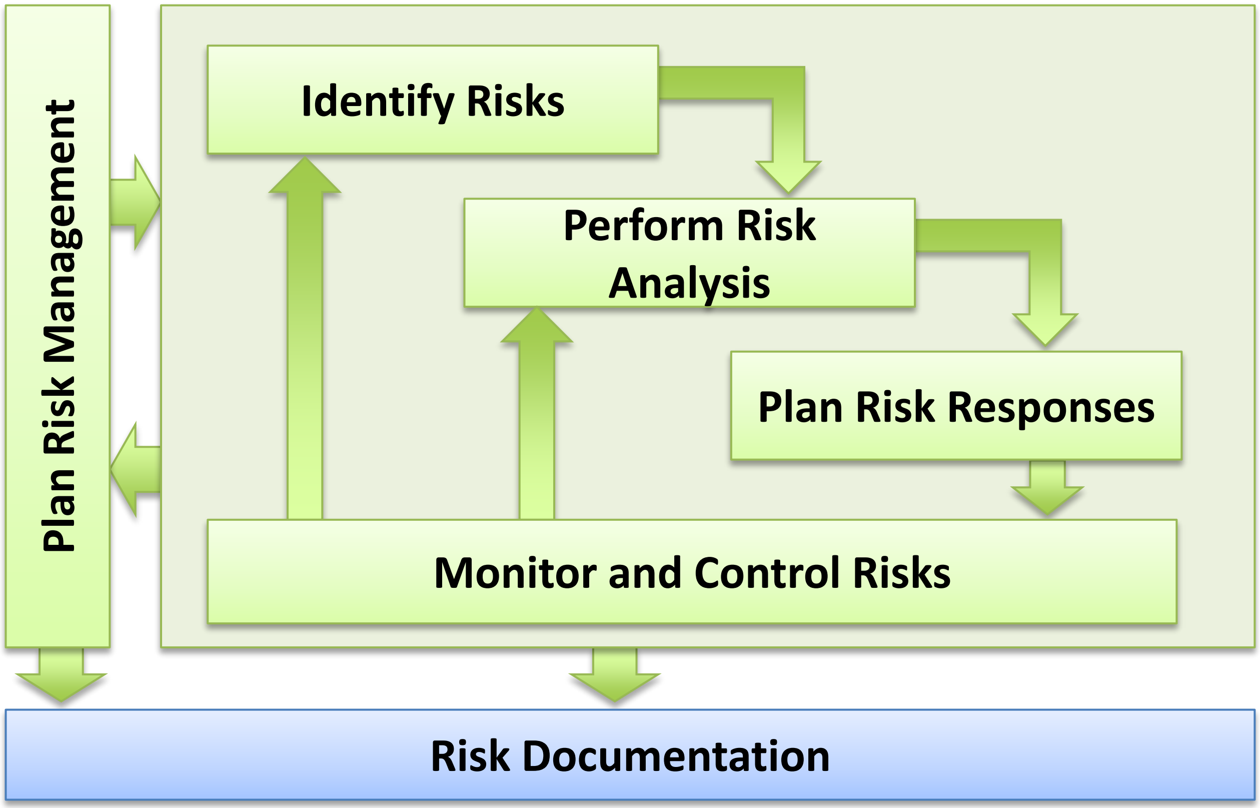
Insert Key Leading Indicators into Dashboard (i.e. CDR Dashboard)

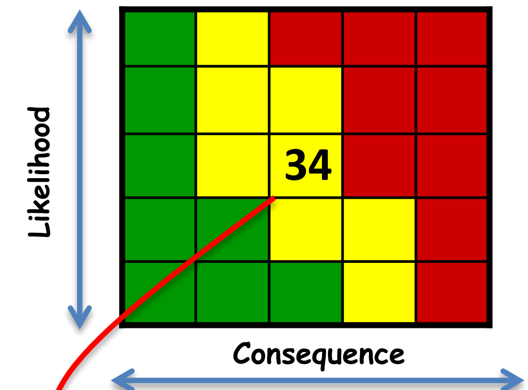
- Provides representation of measure driven gauges that depict trends
- Provide value by representing the collecting, analyzing and synthesizing the data into a format that aids decision making
- In much better position to characterize progress, compare alternatives, assess risk and predict future outcomes
- Objectively assess ***readiness & RISK*** with moving forward (exit)

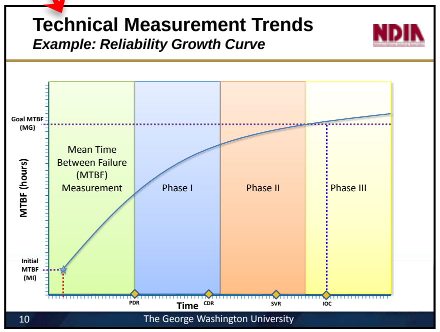
Example Framework for Planning LIs

Leading Indicator	ASR	SRR	PDR	CDR	SVR	FCA	PRR	PCA
Requirements Trends		⊕	⊕	⊕				
System Definition Change Backlog			⊕	⊕				
Interface Trends			⊕	⊕				
Requirements Validation Trends					⊕	⊕		
Requirements Verification Trends					⊕	⊕		
Work Product Approval Trends	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Review Action Closure Trends	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Technology Maturity Trends			⊕	⊕				
Risk Exposure Trends				⊕	⊕			
Risk Handling Trends				⊕	⊕			
Systems Engineering Staffing & Skills Trends	⊕	⊕	⊕	⊕	⊕	⊕		
Process Compliance Trends	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Technical Measurement Trends		⊕	⊕	⊕	⊕	⊕		
Facility and Equipment Availability Trends			⊕	⊕	⊕	⊕	⊕	⊕
Defect and Error Trends				⊕	⊕			
System Affordability Trends				⊕	⊕			
Architecture Trends	⊕	⊕	⊕					
Schedule and Cost Pressure	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕

Risk Management Activities [13]



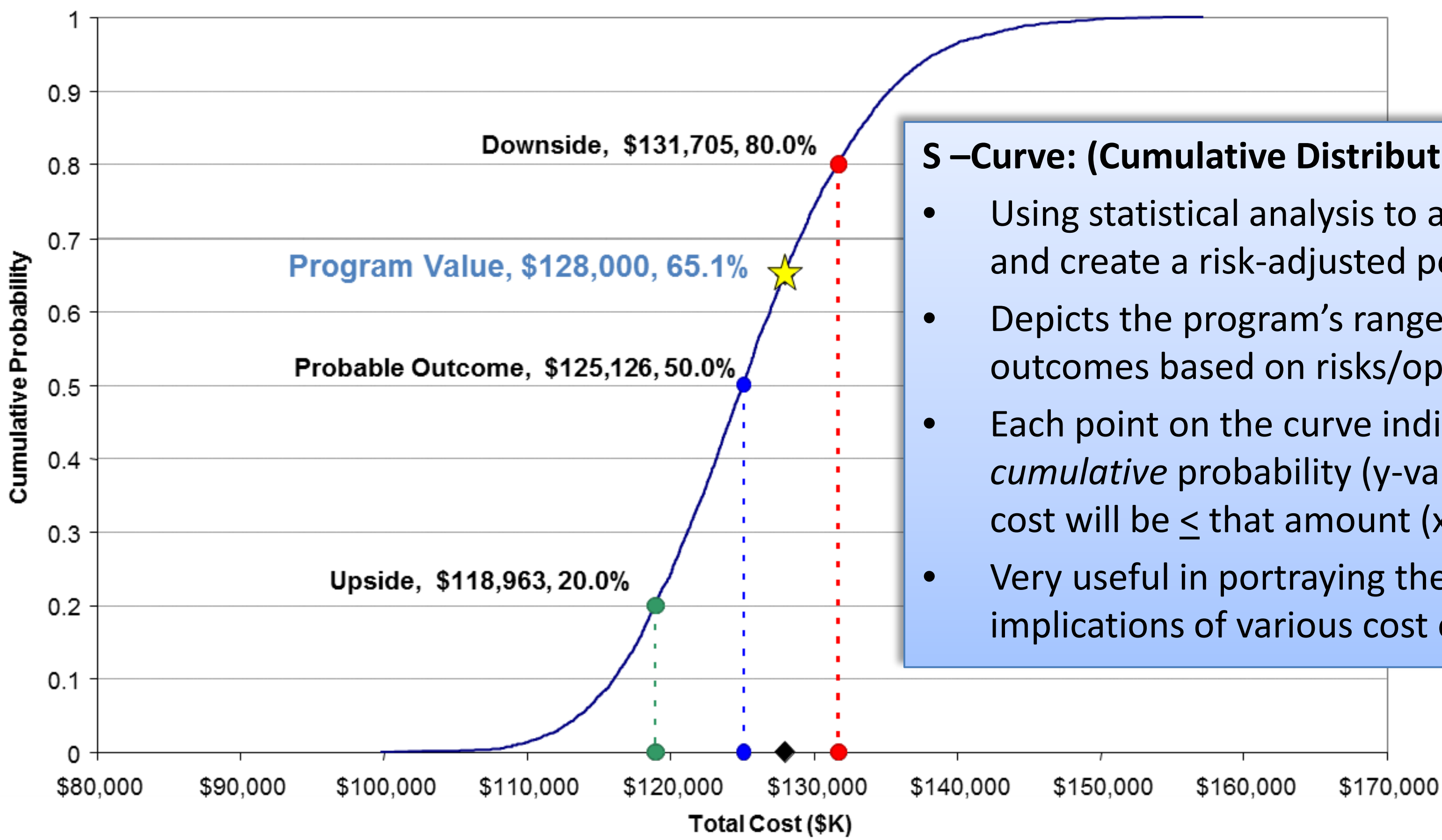




Risk Item #34
Reliability Performance

Leading Indicators Provide Valuable Insight into Execution Risk

S-Curve Analysis[14]



S –Curve: (Cumulative Distribution Function)

- Using statistical analysis to assess cost and create a risk-adjusted point estimate
- Depicts the program's range of potential outcomes based on risks/opportunities
- Each point on the curve indicates the *cumulative* probability (y-value) that the cost will be ≤ that amount (x-value)
- Very useful in portraying the uncertainty implications of various cost estimates

Bottom Line – What is the Cost Confidence (*to Execute*)?

Road Forward - *Scientific Hypothesis*

- Are there key systems engineering metrics that can be monitored that will increase the prediction of a program's ability to meet cost, schedule and technical performance requirements?
  - *Example question: Are we at risk of meeting the planned CDR?*
- Can these factors be evaluated at key decision gates to build confidence in the successful execution of a program?
- Is there a standard scorecard for technical reviews?

➢ H_1: A correlation exists between systems engineering leading indicators and performance

➢ H_2: Those programs that use a defined set of systems engineering measures will perform better

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BACKUP SLIDES

INCOSE's 18 Leading Indicators (1 of 2) [9]

Leading Indicator	Description
Requirements Trends	Rate of maturity of the system definition against the plan. Additionally, characterizes the stability and completeness of the system requirements that could potentially impact design, production, operational utility, or support.
System Definition Change Backlog Trends	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.
Work Product Approval Trends	Adequacy of internal processes for the work being performed and also the adequacy of the document review process, both internal and external to the organization. High reject count would suggest poor quality work or a poor document review process each of which could have adverse cost, schedule and customer satisfaction impact.
Review Action Closure Trends	Responsiveness of the organization in closing post-review actions. Adverse trends could forecast potential technical, cost and schedule baseline issues.
Technology Maturity Trends	Risk associated with incorporation of new technology or failure to refresh dated technology. Adoption of immature technology could introduce significant risk during development while failure to refresh dates technology could have operational effectiveness/customer satisfaction impact.

INCOSE's 18 Leading Indicators (2 of 2) [9]

Leading Indicator	Description
Risk Exposure Trends	Effectiveness of risk management process in managing / mitigating technical, cost & schedule risks. An effective risk handing process will lower risk exposure trends.
Risk Treatment Trends	Effectiveness of the systems engineering organization in implementing risk mitigation activities. If the systems engineering organization is not retiring risk in a timely manner, additional resources can be allocated before additional problems are created.
SE Staffing & Skills Trends	Quantity and quality of systems engineering personnel assigned, the skill and seniority mix, and the time phasing of their application throughout the project lifecycle.
Process Compliance Trends	Quality and consistency of the project defined systems engineering process as documented in SEP/SEMP. Poor/inconsistent systems engineering processes and/or failure to adhere to SEP/SEMP, increase project risk.
Technical Measurement Trends	Progress towards meeting the Measures of Effectiveness (MOEs) / Performance (MOPs) / Key Performance Parameters (KPPs) and Technical Performance Measures (TPMs). Lack of timely closure is an indicator of performance deficiencies in the product design and/or project team's performance.
Facility & Equipment Availability Trends	Availability of non-personnel resources (infrastructure, capital assets, etc.) needed throughout the project lifecycle.
Defect/Error Trends	Progress towards the creation of a product or the delivery of a service that meets the quality expectations of its recipient. Understanding the proportion of defects being found and opportunities for finding defects at each stage of the development process of a product or the execution of a service.
System Affordability Trends	Progress towards a system that is affordable for the stakeholders. Understanding the balance between performance, cost, and schedule and the associated confidence or risk.
Architecture Trends	Maturity of an organization with regards to implementation and deployment of an architecture process that is based on an accept set of industry standards and guidelines.
Schedule and Cost Pressure	Impact of schedule and cost challenges on carrying out a project

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