National Defense Industrial Association
Systems Engineering Division

Practical Software and Systems Measurement

Working Group Report

System Development Performance Measurement

October 2011

Introduction

An issue often cited in studies and reports[1] is the ineffective use of measures and predictive leading indicators to proactively plan and manage the successful acquisition and execution of defense programs. This is reflected as one of the top NDIA systems engineering issues needing to be addressed[2]:

> *Technical decision makers do not have the right information & insight at the right time to support informed & proactive decision making or may not act on all the technical information available to ensure effective & efficient program planning, management & execution.*

In September 2010, the NDIA Systems Engineering Division and Practical Software and Systems Measurement (PSM) sponsored a working group to consider these issues and provide recommendations on a set of information needs, leading indicators, and measures for use by both acquirers and suppliers to obtain better insight into program status and risks to aid ongoing communication and to provide input to decision-making at key program milestones and decision points. This task builds upon prior measurement initiatives and consensus guidance (e.g., PSM, the International Council on Systems Engineering (INCOSE), academia), while integrating experience and practices from adopters as a next logical step in maturing common approaches for systems engineering measurement. The task team used the measurement approach described in the PSM guidance (see PSM in Appendix B) and leveraged the content from the Systems Engineering Leading Indicators Guide (see SELI in Appendix B) as a foundation to identify and define a small set of leading indicators that are very useful on most programs during the Technology Development (TD) and the Engineering and Manufacturing Development (EMD) phases. Though this product is targeted primarily at the NDIA aerospace and defense markets, the results may be broadly applicable into other domains.

Working group objectives included:

- <u>Identify a set of leading indicators</u> that <u>provide insight into technical performance</u> at major decision points for managing programs quantitatively across their life cycle, with emphasis on Technology Development (TD) and Engineering Manufacturing and Development (EMD) phases.
- Build upon <u>objective measures in common practice</u> in industry, government, and accepted standards. Do not define new measures unless currently available measures are inadequate to address the information needs.
- Select <u>objective measures based on essential attributes</u> (e.g., relevance, completeness, timeliness, simplicity, cost effectiveness, repeatability, and accuracy).
- <u>Measures should be commonly and readily available</u>, with minimal additional effort needed for data collection and analysis.

[1] Refer to Appendix B for a summary of key studies and reports related to obtaining greater objective insight into program performance issues.
[2] Top Systems Engineering Issues in U.S. Defense Industry. NDIA Systems Engineering Division, September 2010.http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/Studies/Top%20SE%20Issues%202010%20Report%20v11%20FINAL.pdf

The working group output is this report containing recommendations to OSD as a framework for key information needs, indicators, and measures that could be used in the acquisition and management of defense programs.

This Working Group notes that, in parallel with our work, the Deputy Assistant Secretary of Defense, Systems Engineering (DASD(SE)) was revising the System Engineering Plan Outline (SEPO) the results of which were published in April 2011 (see [SEPO] in Appendix B). Although differing at the detailed level, the recommendations of this Working Group include several indicators that are quite similar to several of the notional examples of indicators expected by the SEPO. The descriptions of the indicators recommended by this Working Group (Appendix C) include pointers to the SEPO where these similarities exist. This convergence of independent OSD and Industry efforts is a positive development that needs to be further nurtured moving forward (see Future Directions below).

Approach

The approach used for this study consisted of a working group core team and public workshop to collect expert input, as depicted in Figure I.

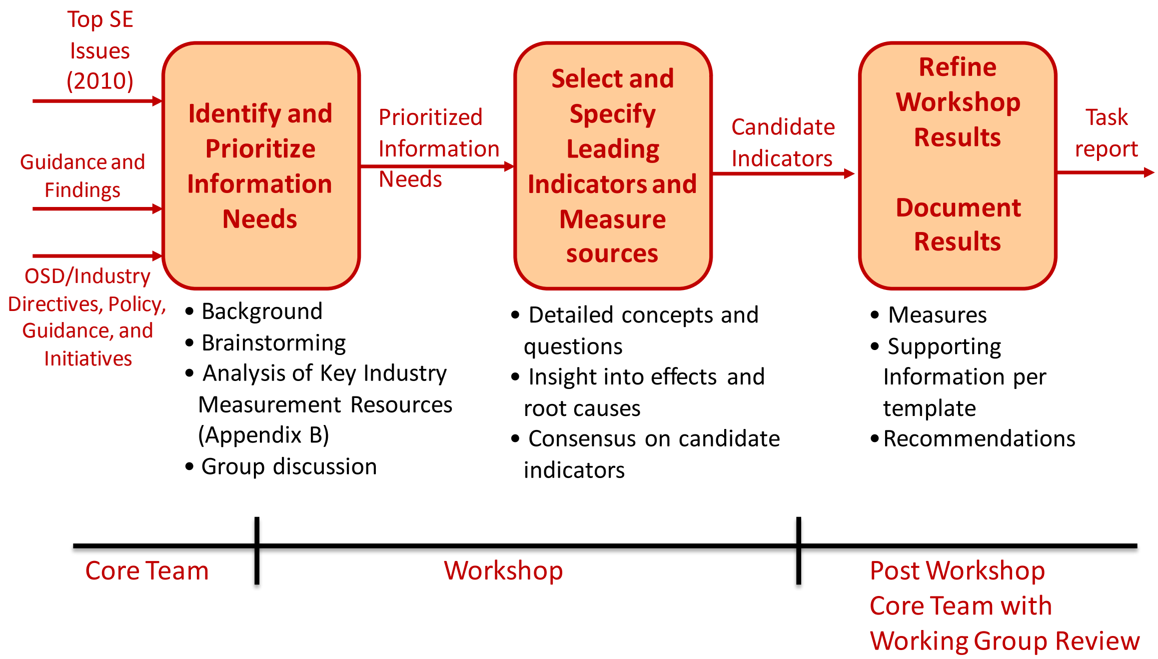


Figure 1. Measurement Study Approach

A workshop was convened March 22-23, 2011 in Washington, D.C. that included 35 participants and measurement experts (ref. Appendix A) from industry, government, and academia. Resources provided as input to the workshop included leading measurement standards, research references, and other assets summarized in Appendix B.

An overview of workshop objectives and DoD imperatives was provided by the workshop core team. Several of the workshop participants also provided briefings or proposals to address measurement-related issues or summaries of applicable measurement research.

The workshop participants identified a set of information needs for which measures are needed to manage programs quantitatively and to support objective decision-making. From this set, a prioritized set of nine information needs, listed in Table 1, was selected by consensus of workshop participants for further analysis by three breakout subteams.

Table 1. Information Needs

Highest Priority Information Needs (drivers for measures considered by breakout teams)	**Other Information Needs** (not considered by breakout teams)
• Requirements • Interfaces • Architecture • Staffing and Skills • Technical Performance • Technology Maturity • Affordability • Risk Management • Manufacturability	• Testability • Requirements Verification and Validation • Defects and Errors • System Assurance • Process Compliance • Work Product Progress • Facilities and Equipment • Change Backlog • Review Action Item Closure

Candidate leading indicators and measures for each of the highest priority information needs were considered by the breakout teams, and further evaluated and refined by the working group core team. Of these, the nine leading indicators listed in Table 2 were determined to have highest importance; that is, most strongly aligned with objectives and criteria including:

- Strongly addresses the information need
- Feasible to produce
- Raw data exists and easily processed
- Already frequently utilized (in common use)
- Provides leading or predictive insight
- Applicable to Technology Development (TD) and Engineering Manufacturing & Development (EMD) phases

Additional candidate indicators were identified (43 in total) but determined to have lower importance relative to these criteria usually being less mature in their application across industry. These measures are available in the SDPMWG working assets and are potential candidates for consideration subsequent to this initial report and set of prioritized recommendations. See the section below concerning "Future Directions."

The working group's preference was to identify high importance indicators that utilized quantitative (objective) measures. The candidate measures for the Architecture, Technical Maturity, Manufacturability and Affordability information needs, while important in their own right, were unable to be addressed by the same caliber of quantitative measures as the other areas. However, the qualitative (subjective) based indicators Technology Readiness Level and Manufacturing Readiness Level are adequate at this time for addressing Technical Maturity and Manufacturability and are included in Table 2. Measures for Architecture and Affordability are recommended to be address in the immediate future (see the "Future Directions" section below).

For each leading indicator recommended, operational descriptions are provided in Appendix C as an aid to consistent understanding, interpretation, and application of the indicators and underlying measures. In many cases, much more detail on these indicators and measures can be obtained from leading measurement standards, guidance, and research as referenced in the Appendix C descriptions and summarized in Appendix B references.

Table 2. Recommendations for Leading Indicators to Address Highest Priority Information Needs

Information Need	Leading Indicators	Recommended Base Measures	Type	Leading Insight Provided
Requirements Evaluate the stability and adequacy of the requirements to understand the risks to other activities towards providing required capability, on-time and within budget. Includes functional, performance, non-functional, maturity. Understand the growth, change, completeness and correctness of the definition of the system requirements.	Requirements Stability (App C-1)	• Number of requirements changes within a time period: total, new, modified, deleted	Quantitative	• Possible engineering impacts (e.g., changes to the architecture, design, implementation, verification, and validation) • Indicates schedule and cost risks
	Stakeholder Needs Met (App C-2)	• Validation Activities (Plan): Cumulative number of activities planned to validate system requirements and technical measures with stakeholders at the end of a reporting period • Validation Activities (Actual): Cumulative number of validation activities actually conducted successfully with stakeholders at the end of a reporting period • Total number of MOEs/KPPs (acquirer mission needs) • Number of MOEs/KPPs fully and partially satisfied by MOPs and TPMs (supplier solution)	Quantitative	For those organizations responsible for defining, allocating, and satisfying mission-level requirements: • Provides early insight (by acquirers and suppliers) into level of understanding of stakeholder needs and satisfaction of mission effectiveness parameters. • Indicates risk to system definition due to inadequate understanding of stakeholder needs; e.g., inability to meet MOEs or mission capabilities. • Indicates if activities to validate operational effectiveness and mission performance are proceeding according to plan. Indicates risk of schedule/cost overruns, post-delivery changes, operational inadequacies/deficiencies, or user dissatisfaction.

Information Need	Leading Indicators	Recommended Base Measures	Type	Leading Insight Provided
Interfaces Evaluate the stability and adequacy of external and internal interfaces to understand the risks to other activities towards providing required capability, on-time and within budget. Understand the growth, change, and correctness of the definition of the external and internal interfaces. Evaluate the integration risks based on the interface maturity.	Interface Trends (App C-3)	• Status of external interface definitions (plan vs. actual) within a time period: total number of interfaces, interfaces completed, interfaces not yet fully defined, interfaces to be resolved	Quantitative	Evaluates the stability and adequacy of the interfaces between the system under development to other systems to which it provide or receives information to understand the risks to other activities towards providing required capability, on-time and within budget.
Staffing and Skills Evaluate the adequacy of the SE effort, skills, and experience provided on the project to meet project objectives.	Staffing and Skills Trends (App C-4)	• Number of Systems Engineering Hours - Planned and Actual • Total Years of Systems Engineering Experience – Planned and Actual (for the system engineers contributing to systems engineering hours)	Quantitative	• May indicate cost or schedule issues • Identifies staffing gaps that may lead to inadequate or late engineering outcomes
Risk Management Determine an estimate of the risk exposure to understand the potential impact to the quality, cost, and schedule of the system solution and the necessary SE effort to manage the exposure. Evaluation of risk treatment plan to assess whether the plan/action items have been properly executed and mitigate the risk.	Risk Burndown (App C-5)	• Number of Identified Risks • Cost Impact of each identified risk occurring • Cost impact of planned actions per risk • Cost impact of actual actions per risk	Quantitative	• Indicates whether the project is effectively managing the project risks as shown by risk burn down over time. • Assessment of risk impacts to the system solution • Assessment of the SE effort in successfully managing the risks

Information Need	Leading Indicators	Recommended Base Measures	Type	Leading Insight Provided
Technical Performance Understand the risk, progress, and projections regarding a system element or system of interest achieving the critical technical performance requirements. Feasibility of performance requirements MOEs, MOPS, KPPs, TPMs.	TPM Trend (specific TPM) (App C-6)	• Planned profile (if appropriate): values targeted to be achieved over time to make progress toward achieving the TPM Goal • TPM Goal: the TPM value targeted to assure achievement of the threshold • Threshold: the TPM value which must be achieved • Achieved: values determined by modeling, estimating or actual measurement at particular points in time	Quantitative	• To what extent is the performance feasible and being achieved per schedule • Provides insight as to where the program schedule may be at risk

	TPM Summary
	(all TPMs)
	(App C-7)
		TPM Status: For each reporting period, a color status (red, yellow, green, blue) based on specific quantitative criteria.	Quantitative	• Indicates whether overall product performance is likely to meet the needs of the user
				• Provides insight into whether the system definition and implementation are acceptably progressing
				  • Early detection or prediction of problems requiring management attention
				  • Allows early action to be taken to address potential performance shortfalls (transition from risk management to issue management)

Technical Maturity Determine the readiness of new technologies and the obsolescence of currently used technologies in order to maintain a useful and supportable technology base.	Technology Readiness Level (TRL) (App C-8)	Technology Readiness Level (TRL) determined by the application of the Technology Readiness Assessment Guidance (see [TRAG] in Appendix B) for each critical technology element	Qualitative	• Risk to the program cost and schedule of immature technologies for critical technology elements • Awareness of technology issues that should be accounted for in early system requirements and design processes • Awareness of technology issues, such as obsolescence, that should be accounted for throughout development, enhancement, and sustainment • Understand the effort required to advance the TRL level

Information Need	Leading Indicators	Recommended Base Measures	Type	Leading Insight Provided
Manufacturability Evaluate the extent to which the product can be manufactured with relative ease at minimum cost and maximum reliability.	Manufacturing Readiness Level (MRL) (App C-9)	MRLs for key system elements, determined using the Manufacturing Readiness Level (MRL) Deskbook (see [MRLD] in Appendix B)	Qualitative	• Awareness of manufacturability issues that should be accounted for in early system requirements and design processes • Risk of design, development, or production impacts to system cost and schedule • The extent to which engineering development and manufacturing processes are integrated
Architecture Evaluates the architecture from the perspectives of quality, flexibility, and robustness. Stability. Adequacy of design rules.	No recommendation at this time; see "Future Directions" below.			
Affordability Understand the balance between performance, cost, and schedule as well as the associated confidence or risk	No recommendation at this time; see "Future Directions" below.			

Benchmarks

“Benchmark” is a shorthand term referring to existing experience data sources and databases. Benchmarks can be extremely important because they may provide an early understanding of the degree of difficulty inherent in a technical solution. Its uses are to provide a quantitative yardstick to measure the degree of improvement for proposed technical objectives against past experience (i.e., the benchmark). A benchmark can also be used to quantify the risk of achieving the performance being evaluated. This allows programs to put in place a variety of actions, such as, changing planned expectations (schedule, performance), additional resources, or investigating alternative technical approaches and ways to reduce the risks.

The workshop attendees discussed an ability to tap into industry databases in order to provide benchmarks for use both by industry and the government. The participants however noted that the databases internal to industry contain proprietary information, and cannot be made available to other competitors or to the government. There was a suggestion that perhaps the government could develop databases that could serve itself and the industry at large. The workshop included a presentation concerning a data repository for software jointly being pursued by the Center for Systems and Software Engineering (CSSE) and the Data and Analysis Center for Software (DACS). The structure could be used to support benchmark information in other areas. The workshop participants agreed this was an important area but no specific conclusion was reached as to next steps. However, all agreed that this area merited further investigation.

Future Directions

The working group considered numerous other candidate indicators and measures that could potentially address the prioritized set of information needs. For several of these information needs, the working group supported the desire for quantitative insight into these objectives, but was unable to provide consensus recommendations on indicators or measures, for one or more reasons including:

- Indicators were determined lower priority for impacting management decision making
- Inability to meet the criteria (essential attributes) for inclusion in this report
- Inconsistent usage across the community of practice
- Lack of predictive or leading insight
- Subjectivity that inhibits consistent use or comparisons across programs

The working group considers many of these potential indicators as promising, and recommends further research and refinement for follow-on work. Programs or companies where these information needs are critical may identify custom indicators. A list of candidate indicators considered of medium importance by the core team is included at the end of Appendix C.

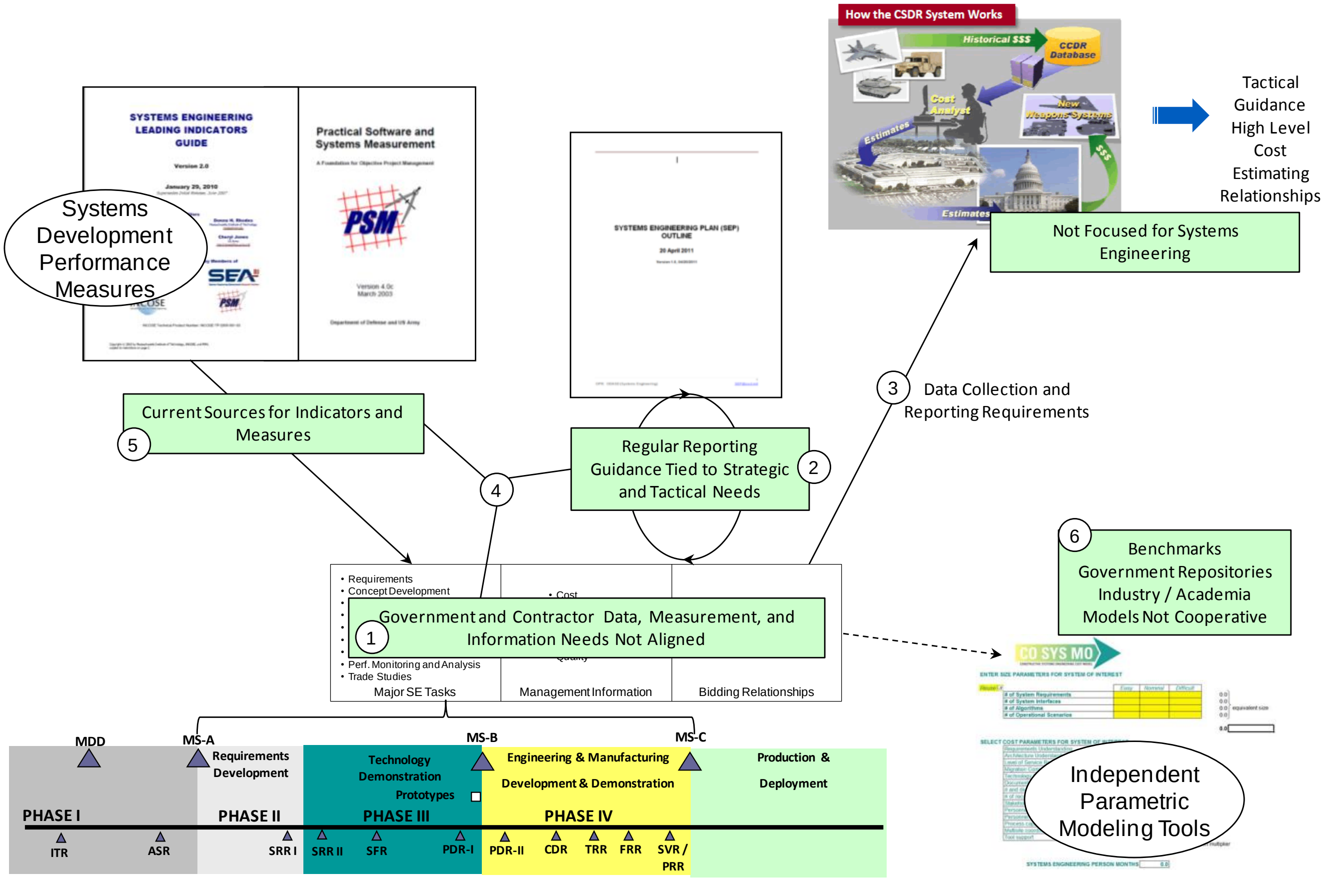
The working group identified a number of areas that need additional work:

- Determine indicators that address the high priority Architecture and Affordability information needs
  Determine and evaluate candidate indicators for the nine other information needs not addressed by the Workshop (see Table 1)
- Include additional SE activities, such as modeling and simulation, and parametric analysis
- Determine an appropriate role for Benchmarking (discussed above)

To address these open areas, the working group plans to establish a road map that will include at least the following tasks, as illustrated below:

1. Build a relationship model for government and contractor information that focuses on information needs, data alignment, and measures
2. Harmonize contractor reporting and government requirements
3. Review and extract existing common data and information need requirements
4. Identify information gaps and remedies
5. Determine the relationships of Systems Engineering activities to information needs
    a. Requirements to needs traceability

   b. Measurement
   c. Parametric analysis
6. Determine how to establish collaboration among the government required data and repository and contractor and academia repositories



Agreement on model and objectives → Gap Analysis Evaluate current practices (SEP, SELI, SDPMWG) → Prioritize Propose next steps

Road Map Development

Summary

The NDIA Systems Engineering Division is pleased to offer this industry input to Deputy Assistant Secretary of Defense for Systems Engineering (DASD (SE)) on recommended leading indicators and measures that could be applied to defense acquisition and development programs. If consistently applied and acted upon, NDIA believes these indicators can greatly enhance visibility of potential program performance issues without adding any additional burden to industry and support objective management decision-making to ensure successful program execution.

NDIA appreciates the opportunity to provide this input, and offers additional support to further these recommendations as applicable. Any additional questions or information needed relative to these recommendations may be addressed to the working group core team, listed in Appendix A.

Appendix A

System Development Performance Measurement Working Group (SDPMWG) - Study Participants

The NDIA Systems Engineering gratefully acknowledges the contributions of the following individuals and organizations in supporting this study.

Measurement Workshop Participants:

Zamawang Almemar	University of Colorado
Dr. Barry Boehm	Center for Systems and Software Engineering
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Geoff Draper	Harris Corporation
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Peter McLoone	Lockheed Martin Corporation
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Dr. Shawn Rahmani	The Boeing Company
Robert C. Rassa	Raytheon Company
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Garry Roedler	Lockheed Martin Corporation
Grant Schmieder	ODDR&E(SE)MA
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David Seaver	PRICE Systems LLC
James Stubbe	Raytheon Company
Todd Tangert	Lockheed Martin Corporation
Kevin Terry	Harris Corporation
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Michael Zsak	Decisive Analytics Corporation (ASD SE)

Additional members of the Working Group were:

Paul Below, SSBB, CSQA	Quantitative Software Management, Inc.
James W. Bilbro	JB Consulting International
Tim Bowden	Alion Science and Technology
Lisa Brownsword	Software Engineering Institute
John Gaffney	Lockheed Martin (retired)
Christopher L. Miller	CTR OSD ATL
Gan Wang	BAE

Additional Contributors included:

Barry Breindel	Independent Consultant
Dennis Kox	Raytheon Company
Dale Iverson	Raytheon Company
Johns Lohse	Raytheon Company
Dan Dechant	Raytheon Company
Brian Wells	Raytheon Company

NDIA appreciatively recognizes the dedicated work of the members of the working group core team for their effort in coordinating this study.

Peter McLoone (Lockheed Martin) - industry lead
Marty Meth (DASD SE) – government lead
Garry Roedler (Lockheed Martin Corporation)
Cheryl Jones (U.S. Army RDECOM-ARDEC, PSM Project Manager)
James Stubbe (Raytheon Company)
Bob Rassa (Raytheon Company)
Alan Brown (The Boeing Company)
Paul Kohl (Lockheed Martin)
Geoff Draper (Harris Corporation)
Gregory Nieman (Lockheed Martin)

Appendix B

Key Measurement Resources and References (Publications, Standards, Research, Directives)

Measurement Standards, Publications, and Guidance

[**SELI]** *Systems Engineering Leading Indicators Guide, Version 2.0,* January 29, 2010.
http://www.incose.org/ProductsPubs/products/seleadingIndicators.aspx

[PSM] *Practical Software and Systems Measurement (PSM): Objective Information for Decision Makers.*
http://www.psmsc.com/Default.asp

ISO/IEC 15939:2007, Systems and software engineering – Measurement process
http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=44344

[TM] *Technical Measurement, Version 1,* December 2005, INCOSE-TP-2003-020-01
http://www.incose.org/ProductsPubs/products/techmeasurementguide.aspx

DoD Resources and References (Legislation, Directives, Studies, Reports)

Weapon Systems Acquisition Reform Act of 2009.
http://www.ndia.org/Advocacy/PolicyPublicationsResources/Documents/WSARA-Public-Law-111-23.pdf

Better Buying Power: A Memorandum for Acquisition Professionals.
Dr. Ashton Carter, OUSD (AT&L). September 2010.
https://dap.dau.mil/Pages/NewsCenter.aspx?aid=157

Naval Probability of Program Success (PoPS). ASN RDA.
https://acquisition.navy.mil/rda/content/view/full/6601

Joint Capabilities Integration and Development Systems (JCIDS), Key Performance Parameters / Key System Attributes (Enclosure B).
https://acc.dau.mil/communitybrowser.aspx?id=267116

Systems Engineering Effectiveness Measures.
Center for Systems and Software Engineering, University of Southern California.
http://csse.usc.edu/csse/research/SEEM/index.html

Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition.
Air Force Studies Board, 2008, The National Academies Press.
http://www.nap.edu/catalog.php?record_id=12065

[SEPO] *Systems Engineering Plan Outline*, April 20, 2011
Office of the Deputy Assistant Secretary of Defense, Systems Engineering
http://www.acq.osd.mil/se/pg/guidance.html

[TRAG] *Technology Readiness Assessment Guidance*, April 2011, revision 13 May, 2011
Assistant Secretary of Defense for Research and Engineering (ASD(R&E))
http://www.acq.osd.mil/ddre/publications/docs/TRA2011.pdf

Manufacturing Readiness Levels Body of Knowledge
Department of Defense Manufacturing Technology Program
http://www.dodmrl.com
In particular at this site:
[MRLD] *Manufacturing Readiness Level Deskbook, July 2011,* Version 2.01

NDIA Resources and References (Studies, Reports, Conferences, Working Groups)

Top Systems Engineering Issues in U.S. Defense Industry.
NDIA Systems Engineering Division, September 2010.
http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/Studies/Top%20SE%20Issues%202010%20Report%20v11%20FINAL.pdf

A Survey of Systems Engineering Effectiveness: Initial Report.
Software Engineering Institute and NDIA Systems Engineering Division, November 2007, CMU/SEI-2007-SR-014.
http://www.sei.cmu.edu/library/abstracts/reports/07sr014.cfm

NDIA Industrial Committee on Program Management (ICPM)
http://www.ndia.org/Divisions/IndustrialWorkingGroups/IndustrialCommitteeForProgramManagement/Pages/default.aspx

NDIA Systems Engineering Conference, October 2010.
DoD presentations on Systems Engineering metrics and systemic findings of program execution issues.
http://www.dtic.mil/ndia/2010systemengr/2010systemengr.html

Appendix C

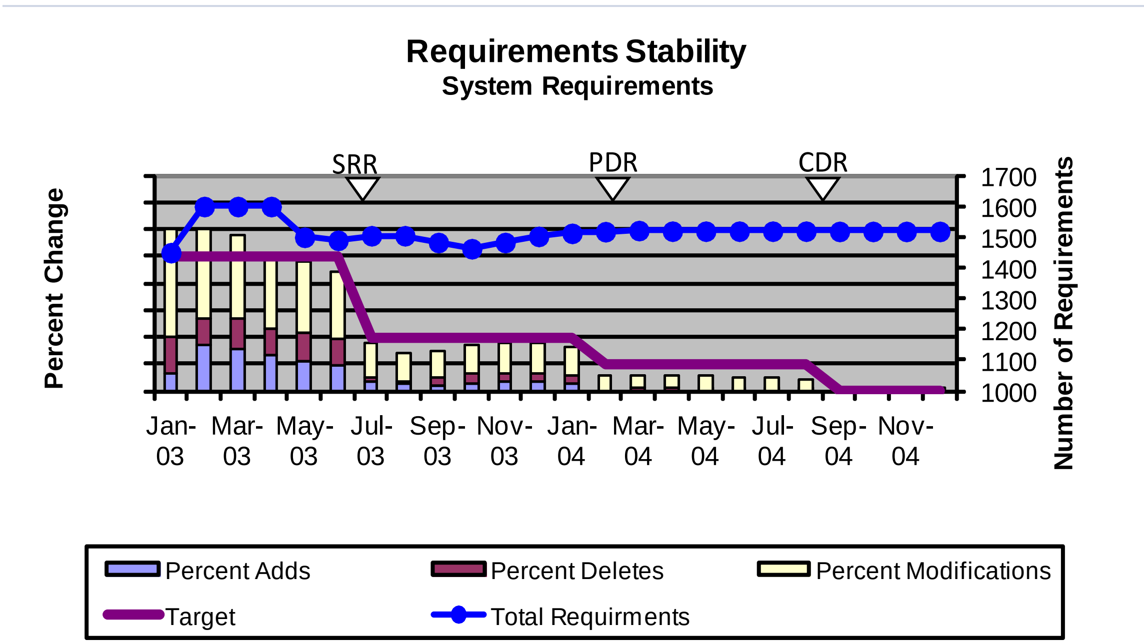
Operational Description Templates for Recommended Leading Indicators

C-1: Requirement Stability

Indicator Name	Requirements Stability
Information Need(s)	**Requirements** Evaluate the stability of requirements to understand the risks to other activities towards providing required capability, on-time and within budget. Understand the growth and change of the definition of the requirements. Note: This indicator can be applied at multiple levels of requirements decomposition (e.g., system, subsystem, component), with traceability established across levels. A key area of concern is the set of system requirements based on contractual specifications.
Question Addressed	Are the system requirements maturing as expected?
Measurable Concept	Use requirements change activity over time to identify unusual volatility in the requirements baseline.
Leading Insight Provided	• Possible engineering impacts (e.g., changes to the architecture, design, implementation, verification, and validation). • Indicates schedule and cost risks.
Base Measures	• Total: Total requirements at the end of the time period (usually a month) • New: The number of new requirements added during the time period • Deleted: The number of requirements deleted during the time period • Modified: The number of requirements modified during the time period
Derived Measures	• Volatility: 100 * (New + Deleted + Modified) / Total
Decision Criteria Interpretation and Usage	The rate of change in requirements may be greater in the early lifecycle as requirements are defined and baselined, but should stabilize significantly as design and development progresses. The threshold should vary depending on the requirements level and lifecycle milestone. For example the threshold for system requirements should be higher prior to SRR than afterwards. The threshold should reflect the maximum change per time period below which the volatility must be kept in order to maintain cost and schedule targets. Thresholds should be informed by historical experience or benchmarking. High rate of change in requirements could indicate potential lack of understanding of stakeholder requirements that may lead to operational or supportability deficiencies.
Additional Considerations	The requirements will be based on “shall” statements (or equivalents) from operational concepts, user requirements, system or subsystem specifications or model based analysis. The requirements emphasis may change depending on the phase of the program. Interface Requirements may be tracked separately. Contractual changes to system requirements are usually driven by ECPs. Changes to other levels of requirements may be externally or internally driven, and may involve adjustments to the scope of contracts or subcontracts among multi-company teams. Denoting the portion of new requirements added during a time period that are reused may be useful. Consider identifying high priority requirements and producing a similar indicator for

Indicator Name	Requirements Stability
	this requirements subset as well. High priority requirements are those that are critical, the most difficult to implement, and often account for a significant portion of the cost and schedule. Requirements are usually allocated, managed and tracked using a requirements management tool. Related industry standard or guide: SELI Section 3.1.

Example



This example shows a lot of churn in the first few months of the program but stabilizes at an acceptable level prior to SRR. Subsequent to SRR, requirements change per month continues at an acceptable level.

Note that this example plots Volatility rather than Stability per se. A few more derived measures are needed in order to provide the stacked bars in this example. The bars are running monthly averages that begin over at each milestone at which the threshold changes.

Note the change in threshold (target) at each milestone.

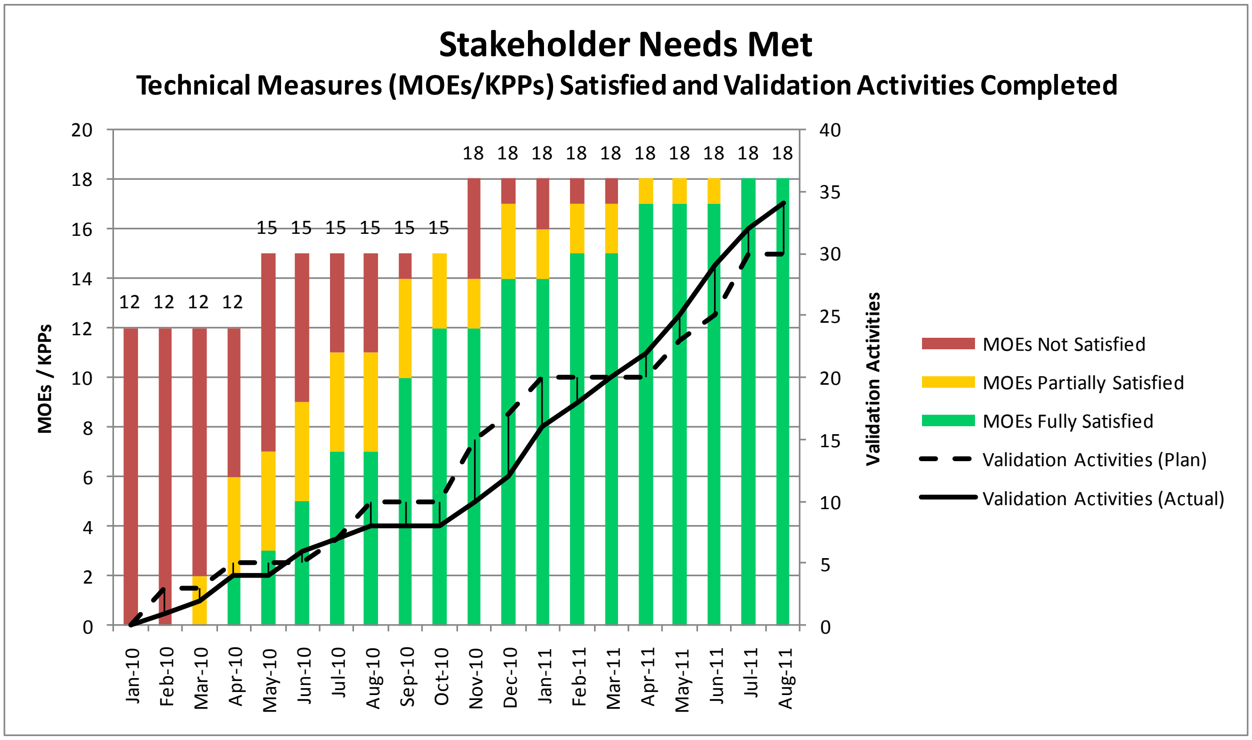
C-2: Stakeholder Needs Met

<table>
<tr><td>Indicator Name</td><td>Stakeholder Needs Met</td></tr>
<tr><td>Information Need(s)</td><td>Requirements
Understand whether the stakeholder needs and mission performance, including Measures of Effectiveness (MOEs), are likely to be met by the system requirements and technical measures.</td></tr>
<tr><td>Question Addressed</td><td>Are the definition and implementation of stakeholder/mission requirements and technical measures suitable to address the mission operational needs?</td></tr>
<tr><td>Measurable Concept</td><td>The extent to which the defined mission requirements are validated and determined suitable to address the operational needs of system stakeholders.</td></tr>
<tr><td>Leading Insight Provided</td><td>For those organizations responsible for defining, allocating, and satisfying mission-level requirements:
• Provides early insight (by acquirers and suppliers) into level of understanding of stakeholder needs and satisfaction of mission effectiveness parameters.
• Indicates risk to system definition due to inadequate understanding of stakeholder needs; e.g., inability to meet MOEs or mission capabilities.
• Indicates if activities to validate operational effectiveness and mission performance are proceeding according to plan.
• Indicates risk of schedule/cost overruns, post-delivery changes, operational inadequacies/deficiencies, or user dissatisfaction.</td></tr>
<tr><td>Base Measures</td><td>• Validation Activities (Plan): Cumulative number of activities planned to validate system requirements and technical measures with stakeholders at the end of a reporting period
• Validation Activities (Actual): Cumulative number of validation activities actually conducted successfully with stakeholders at the end of a reporting period
• Total number of MOEs/KPPs (acquirer mission needs)
• Number of MOEs/KPPs fully and partially satisfied by MOPs and TPMs (supplier solution)</td></tr>
<tr><td>Derived Measures</td><td>• Variance of validation activities conducted (plan vs. actual) relative to schedule or program milestones
• Percentage of MOEs/KPPs fully satisfied by derived technical measures (MOPs, TPMs)</td></tr>
<tr><td>Decision Criteria Interpretation and Usage</td><td>Programs are ultimately judged by stakeholders based on operational effectiveness - the extent to which mission needs and performance measures are satisfied. Insight into the likelihood of achieving mission objectives can be obtained through alignment of technical measures related to validating performance in an operational environment:

<table><tr><th>Technical Measures</th><th>Stakeholder/Context</th><th>Description</th></tr><tr><td>Measures of Effectiveness (MOEs)</td><td>Acquirer / Mission Needs</td><td>Mission-oriented capability measures</td></tr><tr><td>Key Performance Parameters (KPPs)</td><td>Acquirer / Mission Performance</td><td>Critical capabilities and performance parameters</td></tr><tr><td>Measures of Performance (MOPs)</td><td>Supplier / System Capability to Satisfy MOEs/KPPs</td><td>System capability and operational performance</td></tr><tr><td>Technical Performance Measures (TPMs)</td><td>Supplier / Performance</td><td>Performance attributes of system elements</td></tr></table>
It is important to assure flow down and coverage of acquirer MOEs/KPPs by supplier MOPs and TPMs in order to verify mission needs and performance parameters are captured in the system solution. If stakeholder needs are not addressed adequately by requirements or MOEs/KPPs are not adequately measured by associated MOPs and TPMs, then there is a risk that the delivered system will not provide the needed mission capabilities. Note that contractual</td></tr>
</table>

	changes subsequent to contract award may sometimes alter the MOP/KPP entrance criteria for the program. Validation activities, conducted across the life cycle both by acquirers and suppliers, help ensure that system requirements and technical measures are adequate to specify and satisfy mission operational needs. In early program phases (including pre-Milestone A development planning), these activities often are based on projections such as studies, simulations, analyses, or prototypes, and may be independent of a specific technical solution. In later phases, these activities are targeted at validating allocations and measured performance at appropriate levels of the technical solution (e.g., subsystems, components, elements, attributes), and aggregating this data to higher levels of the system hierarchy. Performance models are progressively refined as actual test measures become available. These validation activities conducted with stakeholders across the program life cycle help assure system acceptability during operational testing, deployment, and sustainment. If design and implementation is proceeding without a thorough understanding of requirements validated with stakeholders, this may be a leading indicator of potential mission inadequacy, customer dissatisfaction, or significant rework if the system is later determined by stakeholders to be deficient or unable to satisfy the operational need. Plans for validation of requirements should be in place early and used to drive and monitor system development progress. If validation activities fall behind plan, this may indicate risk of inadequate understanding of mission needs, risk of schedule delays/cost increases, failure to obtain adequate stakeholder involvement, or risk that the system will not be accepted for operational use upon delivery. Validation rates exceeding plan should also be investigated, as this could indicate less stakeholder involvement than needed or potential deficiencies in quality of the validation activities. Corrective actions may be needed when variances against plans exceed acceptable thresholds.
Additional Considerations	This indicator can be applied by acquirers during requirements definition (e.g., during pre-Milestone A development planning) or by suppliers to validate the requirements relative to a mission need or technical solution. This indicator considers the performance of system technical measures at an aggregate level (e.g., set of MOEs/KPPs as a whole), focused on satisfying the external stakeholder (acquirer or user) perspective of assured mission success. Similar indicators can be used for monitoring sets of stakeholder needs or technical measures at other levels of the system hierarchy as applicable, such as Measures of Outcomes (MOOs) applied at the mission or campaign level, or MOPs and TPMs from the perspective of the supplier technical solution. Performance trends for individual technical measures (specific MOEs, KPPs, MOPs, or TPMs) can be managed using separate indicators (see TPM Trend and TPM Summary indicators). This measure could also be used to apply to operational suitability. Collaboration between acquirers and suppliers is fundamental to the effectiveness of this indicator. The early involvement and agreement of mission stakeholders is crucial to validation activities to reach common understandings of objectives and requirements used as a basis for system development. Other measures may also be useful, such as the extent to which critical success factors or quality attributes are judged satisfied by stakeholders. For additional information regarding technical measures (MOEs, KPPs, MOPs, TPMs) see [TM] in Appendix B.

Example



This example depicts the extent to which mission MOEs specified by the acquirer are satisfied, aggregated from performance measures allocated as MOPs and TPMs to components of the supplier technical solution. Performance analysis is conducted as the system requirements and architecture are refined to assure satisfactory mission performance. The amplitude of the stacked bars indicates the total number of MOEs specified; compliance to the set of MOE thresholds (with acceptable margin) are reflected by the colored bars (green, yellow, and red for the count of MOEs for which performance is fully, partially, or not satisfied, respectively). Additional MOEs are specified in two instances as the mission operational concepts and performance needs are refined.

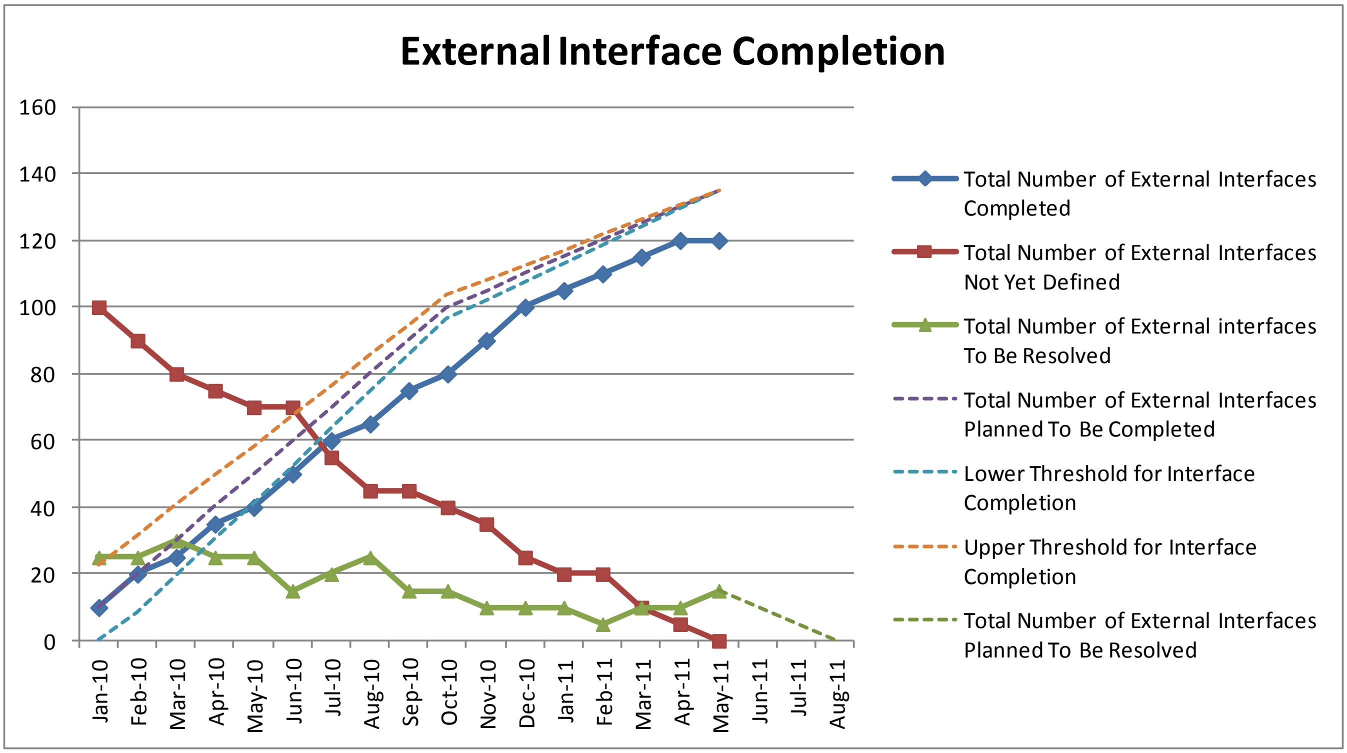
Validation activities are conducted between the supplier and acquirer to ensure the system requirements and technical measures are accurately specified and suitable to address the mission need. In early phases (including pre-Milestone A development planning), these validation activities typically include studies, simulations, prototypes, technical exchange meetings, and other techniques to capture mission knowledge and reflect a shared understanding in system requirements and architecture/design decisions. These validation activities are planned and monitored due to their critical role in shaping downstream life cycle activities and end user acceptance for operational use. In the example above, validation activities fell behind plan during design reviews in the middle of the project, but recovered and completed close to the original schedule even though more operational testing activities were needed to validate the mission need than originally planned.

C-3: Interface Trends

Indicator Name	Interface Trends
Information Need(s)	**Interfaces** Evaluate the growth, change, and correctness of external interfaces.
Question(s) Addressed	Is the definition of external interfaces correct and complete?
Measurable Concept	SE activities associated with correctness and completeness (i.e., approved) and validation of the definition and design of system external non-hardware interfaces.
Leading Insight Provided	Evaluates the stability and adequacy of the interfaces between the system under development to other systems to which it provides or receives information to understand the risks to other activities towards providing required capability, on-time and within budget.
Base Measures	Total Number of External Interfaces at the end of the reporting period (e.g., monthly) Total Number of External Interfaces Completed (determined by the application of explicit criteria) at the end of the reporting period Total Number of External Interfaces Not Yet Defined at the end of the reporting period Total Number of External interfaces To Be Resolved (interface defined but not completed; that is, have outstanding issues) at the end of the reporting period Total Number of External Interfaces planned to be completed by the end of the reporting period Total Number of External Interfaces planned to be resolved by the end of the reporting period
Derived Measures	Total Number of External Interfaces = Total Number of External Interfaces Completed + Total Number of External Interfaces Not Yet Defined + Total Number of External Interfaces To Be Resolved
Decision Criteria Interpretation and Usage	The plans should be based on results expected to be achieved at major milestones. For example, all external interfaces are defined at PDR and all issues are resolved by CDR. For unresolved interfaces use a tolerance band around the plan as Plan Value +/- <some percent> of Plan Value, e.g., Plan Value +/- 10%. The percent used should be based on historical experience on successful programs. For interface definitions use a tolerance band around the plan as Plan Value +/- <some percent> of (Total Interfaces Not Yet Defined). For both unresolved interfaces and interface definitions, investigate if a tolerance is exceeded for the latest reporting period or if the trend over the last several reporting periods is consistently trending toward a tolerance limit. If values are below the lower tolerance limit or trending towards the lower tolerance limit, then identify the dependent program activities impacted, define and evaluate the risks, and take actions to control the exposure. If values are above the upper tolerance limit or trending towards the upper tolerance limit, then the correctness and completeness of the definitions should be reviewed to ensure the quality requirements have been met.
Additional Considerations	A similar approach can be used for internal non-hardware interfaces, for example combat systems. “Complete,” as used here, means the interface has been defined and determined to be complete through analysis or modeling and simulation, but has not been tested. This indicator is addressing tracking interface issues through the completion of their definition. It may also be useful to track interface stability after that point in a manner similar to the Requirements Stability indicator.

	Showing major milestones on the chart is helpful for interpretation. Related industry standard or guide: SELI Section 3.3

Example



"Time Now" is May-11, which is when all interfaces were planned to be completed. However, fifteen remain, with the chart indicating these will be completed within three months. Corrective action was attempted mid-stream but was not sufficient to recover schedule. Since completions were trending toward and crossing the lower threshold much earlier, the basic lesson learned is to take action aggressively when anomalous behavior is first detected.

C-4: Staffing and Skills Trends

<table>
<tr><td>Indicator Name</td><td>Systems Engineering Staffing</td></tr>
<tr><td>Information Need(s)</td><td>Staffing and Skills
Evaluate the adequacy (both number and experience) of the Systems Engineering effort provided on the project to meet project objectives.</td></tr>
<tr><td>Questions Addressed</td><td>Is Systems Engineering Staffing sufficient?
Do the Systems Engineers have the right level of experience?</td></tr>
<tr><td>Measurable Concept</td><td>Compare:
• Actual Systems Engineering Full Time Equivalents (FTEs) to the plan
• Actual Average Experience of Systems Engineering Staff to plan

Analysis of the two together gives a more complete picture of the ability of the SE Staff to accomplish their tasks.</td></tr>
<tr><td>Leading Insight Provided</td><td>• May indicate future cost or schedule issues
• Identifies systems engineering staffing gaps (numbers and/or experience) that may lead to inadequate or late engineering outcomes</td></tr>
<tr><td>Base Measures</td><td>Data is provided for each reporting period (usually monthly):

• Number of Systems Engineering Hours - Actual
• Number of Systems Engineering Hours - Planned
• Total Years of Systems Engineering Experience – Actual
    ○ Number of Systems Engineers contributing to the sum above
• Total Years of Systems Engineering Experience – Planned
    ○ Number of Systems Engineers contributing to the sum above</td></tr>
<tr><td>Derived Measures</td><td>The calculations below are used for both Actual and Planned values:
• FTE Systems Engineering Staff = Number of Systems Engineering Hours in the reporting period / Number of hours in the reporting period for one engineer
• Average Experience of Systems Engineering Staff = Sum of the Total Years of Systems Engineering Experience / Number of Systems Engineers (those directly contributing to the sum in the numerator)</td></tr>
<tr><td>Decision Criteria</td><td>The calculations below are used for both FTE Systems Engineering Staff and Average Experience of Systems Engineering Staff:
• Upper Threshold = (100% + X%) * Plan Number
• Lower Threshold = (100 – X%) * Plan Number
X should be based on historical experience.

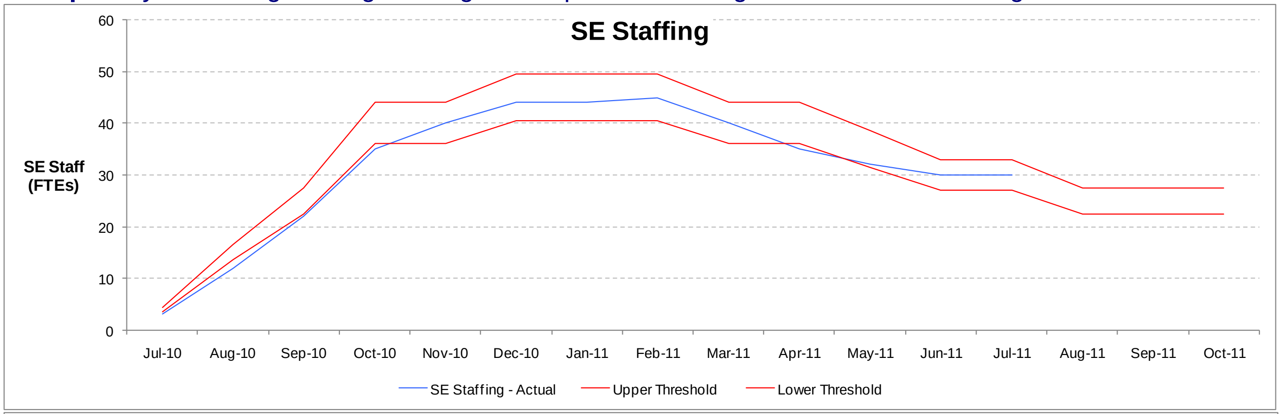
Investigate if a threshold is exceeded for the latest reporting period or if the trend over the last several reporting periods is consistently trending toward a threshold.</td></tr>
<tr><td>Interpretation and Usage</td><td>If actuals are below the lower threshold, schedule, quality or capability may be affected and/or a replan may be needed.

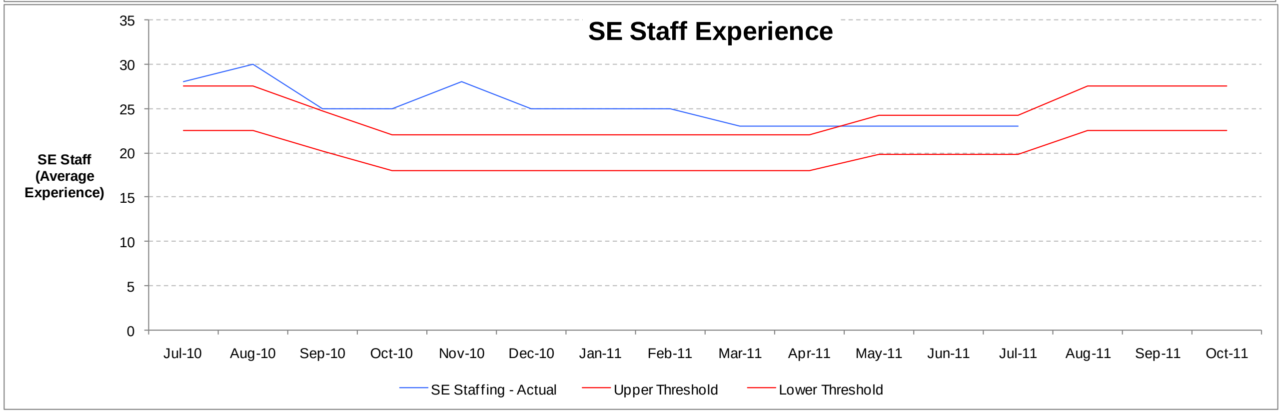
If actuals are above the upper threshold, cost overruns are likely.</td></tr>
<tr><td>Additional Considerations</td><td>Can be accomplished using total hours as well, instead of FTEs.

Consider a drill down capability to provide a similar charts for each skill area or function of importance to program success such as manufacturing reliability system design, circuit design, mechanical design, software, or test.</td></tr>
</table>

Indicator Name	Systems Engineering Staffing
	The entire implementation team may be included: all team members (including subs) and the government. Tracking individual subcontractors separately may be desired. Consider a drill down capability to provide a similar chart for each major systems engineering activity: requirements analysis, architecture and design, IV&V etc. Showing major milestones on the chart is helpful for interpretation. Extra attention should be give at critical phase transitions for the program. For example: • At program start up, insufficient SE staffing is a leading indicator of future poor program performance • Transition from development into IV&V activities requires a change over in the skills of the team (numbers may not change) - not having the right skills on staff is a indicator of potential upcoming issues. While average staff experience may be within thresholds, the experience mix may still be an issue. Consider having the ability to provide a histogram or other mechanism to illustrate the distribution of staff according to experience. Related industry or DoD standard or guide: SELI Section 3.11, SEPO 3.4.2

Example: Systems Engineering Staffing and Experience during Architecture and Design





This project had early understaffing and has been running either within or slightly below the lower threshold. This is balanced somewhat by the higher than planned experience of the team. Extra management attention should be directed to the team to ensure they are successful in achieving their engineering outcomes.

C-5: Risk Burndown

Indicator Name	Risk Burndown
Information Need(s)	**Product Quality, Schedule, and Cost** Determine an estimate of the risks to understand the potential impact to the quality, cost, and schedule of the system solution and the necessary SE effort to manage the risks.
Questions Addressed	What are the risks to the program in terms of cost over time? Are the risks going to impact the system solution? Is the SE effort managing the risks successfully?
Measurable Concept	Compare: • Actual Risk burn down to both the baseline and forecast
Leading Insight Provided	Indicates whether the project is effectively managing the project risks as shown by risk burn down over time. • Assessment of risk impacts to the system solution • Assessment of the SE effort in successfully managing the risks
Base Measures	• Number of identified risks • Cost Impact of each identified risk occurring • Cost impact of planned actions per risk • Cost impact of actual actions per risk

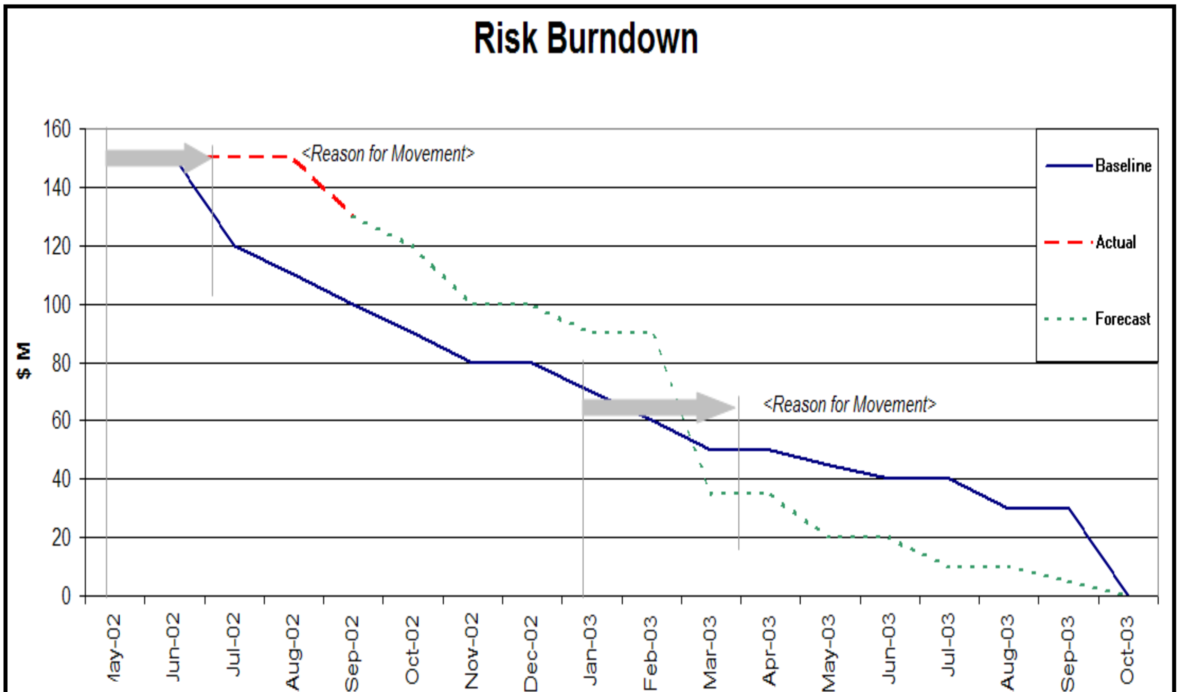
Derived Measures	• Baseline = sum of the Cost Impact of risks identified for those risks remaining over time plotted over the program life
	  ○ The evaluation was performed at contact baseline
	  ○ Once established, baseline values do not change unless the contract is rebaselined
	• Actual = sum of the Cost Impact of risks identified for those risks remaining as addressed plotted up to the current reporting period
	• Forecast = sum of the Cost Impact of risks identified for those risks remaining plotted from the current reporting period forward over time

Decision Criteria	Assess whether risks are being addressed in a timely manner and whether deviations from baseline plan indicate that planned technical solutions are in jeopardy.
Interpretation and Usage	If risks are not being addressed in a timely manner, is the schedule, quality or technical capability affected? Is a replan needed?

Additional Considerations	• Information is readily available, current, and maintained in a Risk Management repository
	• Risk assessment (systemic establishment of factored risk) must be performed and includes:
	  • Risk Identification
	  • Probability of Risk Occurrence
	  • Impact of Risk Occurrence
	  • Criticality of Occurrence (Urgency to Address – If used in a Risk Management process)
	Consider pairing the burndown measure with Risk Treatment trends which indicates whether the project is proactively handling/treating potential problems or risks at the appropriate times in order to minimize or eliminate their occurrence and impacts to the project. Recommended Risk Treatment Charts:
	
	1. Risk Actions – Total, Closed and Over Due

Indicator Name	Risk Burndown
	2. Open Actions by Age 3. Open Risk Actions by Severity 4. Actions Dispositions The Risk Treatment trend charts may plot all data or just concentrate on the highest priority risks. Effective closure of Risk Treatment actions should positively affect risk burndown. Related industry or DoD standard or guide: SELI Section 3.9, SEPO Section 3.3

Example: Risk Burndown Chart



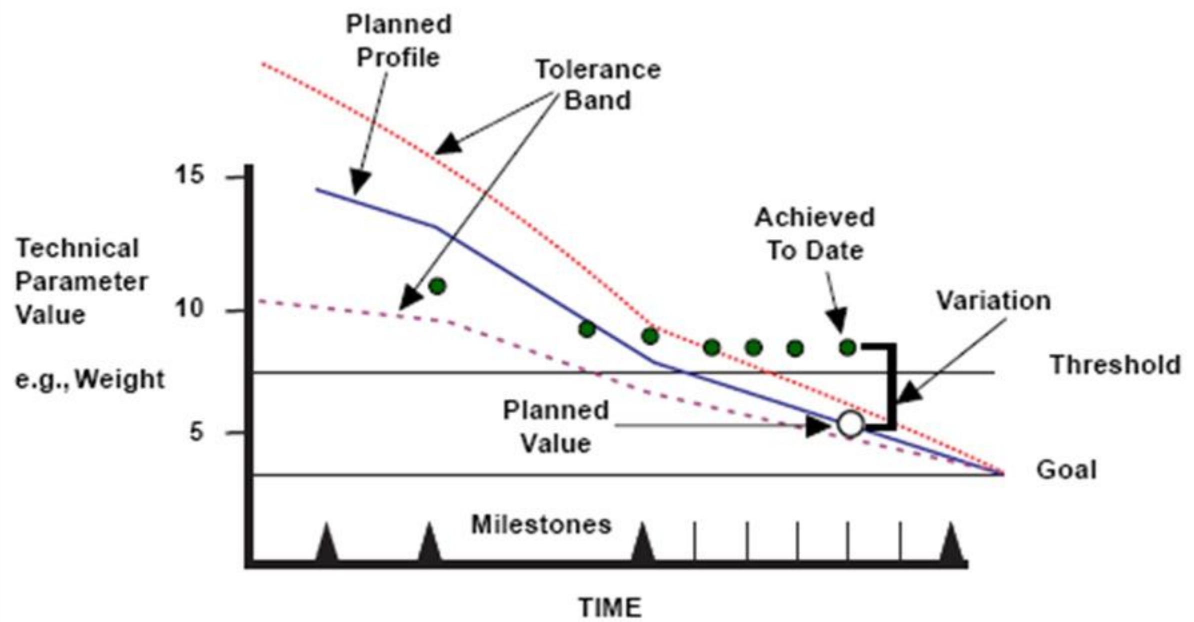
Source: SELI

The graph illustrates the planning and tracking of the risk exposure in terms of cost ($M). The plot of the actual risk exposure burndown shows a slow start. The project team projected the burndown for the remainder of the project to identify whether the risk exposure could be reduced to an acceptable level as the project proceeds and where there were realistic opportunities that could significantly reduce the exposure.
To build confidence in the projection, the project team needed to determine the reason for any significant movement (positive or negative). The first movement was due to late project ramp-up and requirements changes. The second movement was where the project team would be able to insert technology to eliminate a set of risks.

C-6: TPM Trend (specific TPM)

Indicator Name	TPM Trend
Information Need(s)	**Technical Performance** Understand the risk, based on progress, and projections, of achieving the critical system and/or major subsystem technical performance measures. Critical technical measures are those required to achieve KPP's.
Question Addressed	Will the project achieve the goal for each critical technical measure?
Measurable Concept	Track modeled, estimated or actual TPM values against the expected profile or the goal for the TPM over time
Leading Insight Provided	• To what extent is the performance feasible and being achieved per schedule • Provides insight as to where the program schedule may be at risk
Base Measures	• Planned profile (if appropriate): values targeted to be achieved over time to make progress toward achieving the TPM Goal • TPM Goal: the TPM value targeted to assure achievement of the threshold • Threshold: the TPM value which must be achieved • Achieved: values determined by modeling, estimating or actual measurement at particular points in time
Derived Measures	Depends on the particular TPM
Decision Criteria Interpretation and Usage	• Tolerance band (may be one sided): a range around the planned profile regarded as acceptable • Values outside the tolerance band or trending toward a tolerance limit over several months require further evaluation
Additional Considerations	The expectation is that a given project would have a selective (small) list of critical TPMs tracked in this manner. Related industry or DoD standard or guide: SELI Section 3.13, SEPO Section 3.6, particularly the Reliability Growth Curve

Example:



Source: SELI

This example depicts a performance profile over time for a single TPM of interest (e.g., weight) relative to program milestones. Planned values are plotted with allowable tolerance bands (the range of acceptable high and low measured values). Actual measured values are plotted regularly (e.g., monthly or at significant program milestones) depicting variation relative to plan. Thresholds are established for performance targets, which may include both required and objective values. Corrective actions may be needed when measured values exceed allowable bounds (as in this example), in order to bring performance back in alignment (i.e., “return to green plan”).

Thresholds and performance margins typically narrow and become more stringent (less tolerance) as the schedule progresses.

The representation shown in this example is typical, but indicators may vary in form depending on the characteristics of the parameter being measured.

C-7: TPM Summary (all Critical TPMs)

Indicator Name	TPM Summary
Information Need(s)	**Technical Performance** Understand the risk, progress, and projections regarding a system element or system of interest achieving its critical technical performance requirements.
Question(s) Addressed	Are there performance issues that affect the likelihood of program success?
Measurable Concept	Summarize the history, current status, and outlook for the most important TPMs at a point in time
Leading Insight Provided	Indicates whether overall product performance is likely to meet the needs of the user Provides insight into whether the system definition and implementation are acceptably progressing. • Early detection or prediction of problems requiring management attention. • Allows early action to be taken to address potential performance shortfalls (transition from risk management to issue management).
Base Measures	TPM Status: For each reporting period, a color status (e.g., red, yellow, green, blue) based on specific quantitative criteria.
Derived Measures	None
Decision Criteria Interpretation and Usage	Investigate and, potentially, take corrective action when the values of the MOEs/MOPs/TPMs meet yellow or red quantitative criteria or a trend is observed per established guidelines. Criteria are usually based on specific tolerance bands frequently derived from contractual requirements.
Additional Considerations	• Assumes MOE/MOP/TPM measurement records are maintained & current. This includes accurate and current measured values from analysis, prototype, and test. • The color rating must be based on specific quantitative values agreed to by all stakeholders. • Consider also including for each TPM, the date of the determination of the current value for the TPM, the basis of the determination (modeling and analysis, prototyping, or actual product testing using an appropriate performance scenario), the value, and the green threshold. • TPMs should be derived from KPPs or other critical requirements that affect the technical success of the project. • Action strategy for failure to remain within defined profiles should be defined ahead of time (risk mitigation planning) to improve likelihood of implementation and avoid management paralysis. Mitigation plans should consider any coupling to other TPMs. • Comparisons of achieved results vs. needed profiles must be based on the same criteria, scenario, etc., to avoid “gaming”. • TPMs should be reported with error tolerances to indicate the confidence level or uncertainty of the analysis models or test results. • It is useful to understand the MOE/MOP/TPM sensitivity to changes in other parameters. • Applicable to all phases of the life cycle through Production and Deployment . • Providing the locations of major milestones is helpful for interpretation. • Should keep the chart to no more than a dozen TPMs. May need to change the set as conditions change. • The ability to drill down to additional information on a TPM of interest (e.g., provide TPM Trend) is very useful. • Related industry standard or guide: SELI Section 3.13, SEPO Section 3.6

Example 1

Technical Performance Measures (TPMs)

	Jul	Aug	Sep	OCt	Nov	Dec	Jan	Feb	Mar	Apr
TPM1	G	G	G	G	Y	Y	Y	G	G	G
TPM2	G	G	G	G	R	R	R	R	Y	Y
TPM3	G	G	G	G	G	G	G	G	G	G
TPM4	G	Y	Y	Y	G	G	G	G	G	G
TPM5	Y	Y	Y	Y	Y	Y	Y	G	G	G
TPM6	G	R	R	R	Y	G	G	G	G	G
TPM7	G	G	G	G	G	Y	Y	Y	Y	G

Source: SELI

Time Now

This example depicts the status over time for a set of program-specific TPMs. Let us assume PDR was in August and CDR will be in March. Consequently, TPM results to date are from analysis, modeling and simulation, possibly some prototyping. At a high level, this shows good progress to date (Nov) on two of the three TPMs that were yellow or red at PDR, with the third anticipating Return to Green by CDR. However, the latest modeling results for TPM2 show a serious performance problem, the resolution of which is expected to go beyond CDR. There is expected to be a side effect on TPM7 once modeling runs are completed in the coming month. 'Return to Green' plans are being worked for both and will be presented next month.

Example 2

Name	Responsible Position /IPT	KPP or KSA	Performance Spec.	PDR Status Actual	MS B Status Actual	CDR Status Actual	MS C Status Planned	FRP Status Planned
Aerodynamic Drag (count)	SE IPT		<222	225	223	220	187	187
Thermal Utilization (kW)	SE IPT		<60	56	59	55	51	50
Electrical Power Usage (kW)	SE IPT		<201	150	185	123	123	123
Operating Weight (lb)	SE IPT		<99,000	97,001	101,001	97,001	85,540	85,650
Range (nm)	SE IPT		>1,000	1,111	1,101	1,111	1,122	1,130
Average Flyaway Unit Cost (number)	SE IPT		<1.5	1.3	1.58	1.37	1.35	1.32

*Note: Margin is 10%

Source: SEPO

This example shows critical TPM values at important milestones during the program. While several TPMs were not initially satisfactory, all were brought within specification by CDR and within margin by Milestone C.

C-8: Technology Readiness Level (TRL)

Indicator Name	Technology Readiness Level (TRL)
Information Need(s)	**Technical Maturity** Determine the readiness of new technologies in order to understand the risks of incorporation into a program or system.
Question Addressed	Is the maturity of new technologies associated with critical technology elements consistent with the current point in the lifecycle? Are future plans for maturing these technologies adequate to meet program needs?
Measurable Concept	Use a well structured interview based assessment with well defined criteria for each TRL to determine the appropriate TRL for each critical technology element and identify the risks associated with that achievement
Leading Insight Provided	• Risk to the program's cost and schedule of immature technologies for critical technology elements • Awareness of technology issues that should be accounted for in early system requirements and design processes. • Awareness of technology issues, such as obsolescence, that should be accounted for throughout development , enhancement, and sustainment. • Understand the effort required to advance the TRL level
Base Measures	• Technology Readiness Level (TRL) determined by the application of TRAG (see TRAG. Appendix B) for each critical technology element
Derived Measures	• Planned TRL profile: target TRL over a period of time for an identified critical technology element • Actual TRL profile: assessed TRL over a period of time for an identified critical technology element • Number of critical technology elements at the planned/targeted level for a given milestone
Decision Criteria Interpretation and Usage	• TRLs should be used as measures to (1) define current level of technology maturity (2) identify & discuss maturity shortfalls and associated costs and risks, (3) provide the basis for focused technology maturation and fact based risk management. While time phased TRL definitions provide best practice exit criteria for assessing technology maturity and risk for each phase of the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System, they should not be viewed as fixed thresholds (e.g, pass/fail criteria).

Additional Considerations	• TRLs are determined by conducting Technology Readiness Assessments (TRAs) relative to established DOD TRA criteria.
	• TRAs and TRLs should be conducted starting early and continuing periodically throughout the product development life cycle so potential risk areas can be identified, avoided if possible, and mitigated before they negatively impact the program.
	• Technology readiness plays a role in manufacturing readiness; MRLs and TRLs should be used in an integrated fashion.
	• Critical technology elements should have a maturation plan similar to a risk mitigation plan with the plan activities integrated into the IMP and IMS.
	• Users need to keep in mind several limitations of TRLs:
	    • TRLs do not account for the criticality of a product or technology to the system as a whole. How difficult would it be to replace it if it is later shown to be unsuitable (e.g., early lab prototypes are promising but scaling to a more operational environment fails)?
	    • TRL definitions combine multiple aspects or attributes of quality and readiness, making it difficult to determine how a particular attribute contribute to the readiness of a product or technology – and which of the attributes are important to a specific system context.
	• Related industry or DoD standard or guide: TRAG (see Appendix B)

Example

System Milestone / Technical Review	TRL (Plan)	TRL (Actual)	MRL (Plan)	MRL (Actual)	Comments / Risk Action Plan
ITR	TRL 2	TRL 3	MRL 2	MRL 2	Analysis model based on ABC study
ASR	TRL 3	TRL 3	MRL 3	MRL 3	Lab validation of ASIC mfg concept
MS A	TRL 4	TRL 3	MRL 4	MRL 3	Study funding delayed 30 d. TRA completed.
SRR	TRL 5	TRL 4	MRL 5	MRL 3	Mechanical packaging ICD validation issues. Supplier facility contention elevated.
SFR	TRL 6	TRL 5	MRL 6	MRL 5	Prototyped XYZ subsystem w/ test bed I/F. Investigating low yield on lot 6 wafer fab.
PDR / MS B	TRL 6	TRL 6	MRL 6	MRL 6	Dwgs on plan. Tin whisker fab issue ok. Producibility plan approved.
CDR	TRL 7		MRL 7		Evaluating alternative µW feeds (risk #23).
TRR	TRL 7		MRL 8		
SVR (FCA PRR)	TRL 7		MRL 8		
MS C	TRL 8		MRL 9		
FRP Decision Review	TRL 9		MRL 10		

This example depicts a TRL/MRL maturation plan aligned with system milestones and technical reviews (as described in the MRL Deskbook). Actual TRL/MRL values achieved relative to plan are determined via standard readiness assessment criteria. Actuals are highlighted (e.g., blue, green, yellow, red) to depict the extent to which TRL/MRL maturation is on plan. A brief summary of key accomplishments is provided for each readiness level assessment as rationale for assigned ratings or gaps relative to plan. Action plans are defined to mitigate identified technology or manufacturing risks. In this example, assessed TRL/MRL levels both lagged slightly behind plan for several successive milestones but have recovered by PDR. The program is currently in the detailed design phase with plans to achieve TRL 7 and MRL 7 by CDR.

Technology readiness and manufacturing readiness go hand in hand; it is quite common for manufacturing readiness to be paced by technology readiness or design stability. Manufacturing processes will not be able to mature until the product technology and product design are stable. TRLs and MRLs are therefore provided on a single indicator to facilitate these comparisons for an overall assessment of technology/manufacturing maturity and program risk, and to encourage the coordinated integration of concurrent design, development, and manufacturing processes, activities, and resources. TRL and MRL together provide a common framework to determine the risk and efforts required to mature a technology or manufacturing capability.

Indications of immature technology or manufacturing readiness relative to the appropriate stage in the program life cycle are considerations for management decision making and development of mitigation plans to address identified risks.

This example is for a single critical technology element. Multiple indicators may be needed to depict additional elements.

C-9: Manufacturing Readiness Level (MRL)

Indicator Name	Manufacturing Readiness Level (MRL)
Information Need(s)	**Manufacturability** Evaluate the extent to which the product can be manufactured with relative ease at minimum cost and maximum reliability.
Question Addressed	Is the system being designed and developed producible and are there significant risks associated with manufacturing processes and transition readiness that must be addressed?
Measurable Concept	Assess the manufacturability and risks associated with the design, development, and/or production of critical technology elements as well as key manufacturing technologies & processes. MRLs provide a uniform metric to measure and communicate manufacturing risks and readiness to successfully transition to the next phase of product development.
Leading Insight Provided	• Awareness of manufacturability issues that should be accounted for in early system requirements and design processes. • Risk of design, development, or production impacts to system cost and schedule. • The extent to which engineering development and manufacturing processes are integrated.
Base Measures	• Manufacturing Readiness Level: MRL 1 through MRL 10, time phased to support effective and timely transitions of critical technology elements and key manufacturing technologies & processes. • Manufacturing risks identified
Derived Measures	• Planned MRL profile: target MRL over a period of time for an identified critical technology element and key manufacturing technologies & processes. • Actual MRL profile: assessed MRL over a period of time for an identified critical technology element and key manufacturing technologies & processes.
Decision Criteria Interpretation and Usage	• MRLs should be used as measures to (1) define current level of manufacturing maturity (2) identify & discuss maturity shortfalls and associated costs and risks, (3) provide the basis for focused manufacturing maturation and fact based risk management. While time phased MRL definitions provide best practice exit criteria for assessing manufacturing maturity and risk for each phase of the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System, they should not be viewed as fixed thresholds (e.g., pass/fail criteria).
Additional Considerations	• MRLs are determined by conducting Manufacturing Readiness Assessments (MRAs) relative to established industry best practice MRL exit criteria. • MRAs and MRLs are most effective when conducted early in the product development life cycle so potential risk areas can be identified, avoided if possible, and mitigated before they negatively impact the program. • Threads related to manufacturing risks include: capabilities of technology and industrial base; design maturity; materials; cost and funding; manufacturing process capability and control; quality management; personnel capability and skills; manufacturing facilities; integration of manufacturing with overall program planning, scheduling, and controls. • Related industry or DoD standard or guide: MRLD (see Appendix B)

Example

MRLs share a common indicator with Technology Readiness Levels (TRLs). See Section C-7 for an example and interpretation.

C-9: Indicators of Medium Importance by Information Need

Information Need	Indicators of Medium Importance
Requirements	Threshold changes
Requirements	Requirements TBDs
Requirements	Requirements Feasibility
Interfaces	Interfaces Integrated and Verified
Architecture	Architectural Changes
Affordability	KPP Related Late Finishes
Affordability	Cost Driver Trend
Technology Maturity	Integration Maturity Checklist Score
Technology Maturity	System of Systems Integration Maturity
Technology Maturity	CTE Fallback Planning
Technology Maturity	Reliability Growth
Technical Performance	Reliability Technical Debt
Technical Performance	Defect Detection by Phase
Technical Performance	Cumulative Defects Detected in Phase
Risk Management	Risk Identification