SYSTEMS ENGINEERING LEADING INDICATORS GUIDE

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1. ABOUT THIS DOCUMENT

This Systems Engineering Leading Indicators Guide is the result of a project initiated by the Lean Aerospace Initiative (LAI) Consortium in cooperation with the International Council on Systems Engineering (INCOSE), Practical Software and Systems Measurement (PSM), and Systems Engineering Advancement Research Initiative (SEARI). Leading measurement and systems engineering experts from government, industry, and academia volunteered their time to work on this initiative. This document is issued by INCOSE as document number INCOSE-TP-2005-001-02.

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2. EXECUTIVE SUMMARY

Several policies calling for improved systems engineering on programs were released by DoD and the services during 2004[1]. During this period, the Lean Aerospace Initiative (LAI) Consortium was tasked with assisting with the systems engineering revitalization activity. In June 2004, an *Air Force/LAI Workshop on Systems Engineering for Robustness*[2] was held to establish the groundwork for several initiatives in support of systems engineering revitalization. One of these initiatives focused on ***leading indicators for evaluating the goodness of systems engineering on a program***. In December 2005, the beta version of this document was released, describing the initial set of SE Leading Indicators. This initial set reflected the subset of possible candidate indicators that were considered to be the highest priority by the team, recognizing that the set was not exhaustive. In June 2007, this Version 1.0 document was released following the completion of a validation phase which included pilot applications of the leading indicators, a research study, various workshops, and an industry survey. Recommendations and further guidance on interpretation has been added based on results of the validation phase. Additional SE Leading Indicators will be added in future updates as these are identified, defined, and evolved.

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 affect 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. Leading indicators aid leadership in delivering value to customers and end users, while assisting in taking interventions and actions to avoid rework and wasted effort.

Who Developed the SE Leading Indicators? Subsequent to the June 2004 workshop, the "SE Leading Indicators Action Team" was formed under the auspices of LAI, comprised of engineering measurement experts from industry, government and academia, involving a collaborative partnership with INCOSE[3] . Mr. Garry Roedler of Lockheed Martin and Dr. Donna Rhodes of MIT co-led the effort. Leading SE and measurement experts from LAI member companies, INCOSE, SSCI[4], and PSM[5] volunteered to serve on the team. The team held periodic meetings and used the ISO/IEC 15939 and PSM Information Model to define the indicators. To date, thirteen SE leading indicators have been developed, as summarized in Table 1.

What Problem do SE Leading Indicators Address? To effectively manage programs, leaders need access to leading indicators. Leading indicators provide insight into potential future states to allow management to take action before problems are realized. While there are some leading indicators that cover the management aspects of program execution (e.g., earned value, etc.), we lack good leading indicators specifically for systems engineering activities.

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[1] Policies include Policy for Systems Engineering in the DOD, 20 Feb 04; Assistant Secretary of the Air Force for Acquisition, Dr Sambur , 9 Apr 03, Policy Memo 03A-005 titled Incentivizing Contractors for Better Systems Engineering; Memo 04A-001 titled Revitalizing AF and Industry Systems Engineering Increment 2

[2] Rhodes, D. Ed, Report on the AF/LAI Workshop on Systems Engineering for Robustness, July 2004, http://lean.mit.edu

[3] INCOSE (International Council on Systems Engineering) is the leading professional society for systems engineering. INCOSE has developed guidance materials on systems engineering measures, and both editors of document have served as former chairs of the INCOSE Measurement Working Group. INCOSE is collaborating with LAI on this effort, and is targeted as the long term owner for guidance developed under this LAI project.

[4] SSCI (Systems and Software Consortium Inc.) is collaborating with LAI on systems engineering initiatives.

[5] PSM (Practice Software and Systems Measurement) has developed foundational work on measurements under government funding. The LAI effort is using formats developed by PSM for documenting of the leading indicators.

Who are the Primary Users of the Leading Indicators? The primary users are the program specific systems engineering leadership, program management, and IPT leadership who use the indicators to assess and make adjustments for assuring systems engineering effectiveness of the program. Selected indicators may also be used by the program customers, program partners, and program suppliers depending on phase of program and nature of the contractual relationship. Secondary users include executive and business area management, as well as process owners, for the purpose of predicting the overall effectiveness of systems engineering within and across a program, and for early detection of problems that require management attention.

How do Leading Indicators Differ from Conventional SE 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 the 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, interpreted, and used to provide a forward looking perspective*.**

How do SE Leading Indicators relate to Current Organizational SE Measurement Practices? Most organizations have an organizational measurement plan and a set of measures. These leading indicators are meant to augment the existing set of measures. For optimal efficiency these should be implemented via the organization's measurement infrastructure (typically based on CMMI® practices), thereby enabling mechanized data gathering, analysis, and evaluation. It should also be noted that leading indicators involve use of empirical data to set planned targets and thresholds. Where organizations lack this data, expert opinion may be used as a proxy to establish initial targets and thresholds until a good historical base of information can be collected, but should not be relied on as a long term solution for measurement projections. Rather, organizations must build the collection of the historical measurement data into its collection practices.

What is the Expected Impact? These leading indicators have been specifically selected to provide insight into key systems engineering activities across the phases of a program.

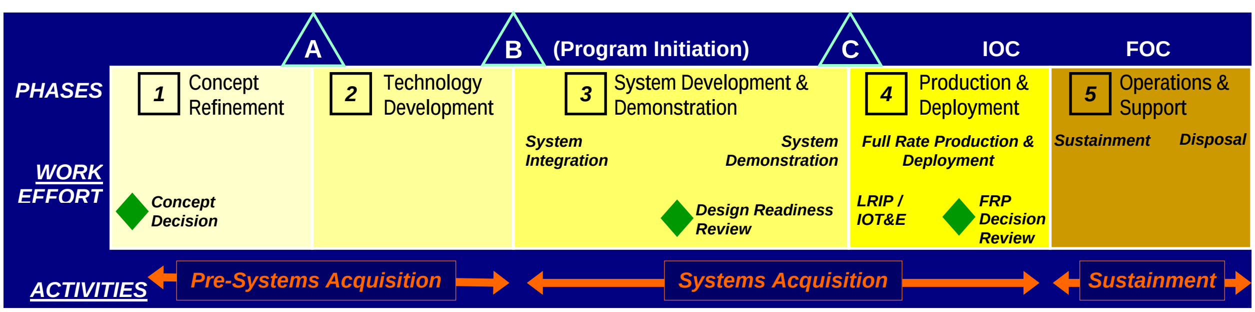


Figure 1 - The Defense Acquisition Management Framework

Figure 1 - The Defense Acquisition Management Framework, depicts the United States Department of Defense (DoD) acquisition life cycle phases for a defense program. These phases were established and described by DoD Instruction 5000.2 and the associated Defense Acquisition Guidebook. This process is a continuum of activities for managing all defense acquisition programs. Appropriate tailoring of the detailed measurement information specifications may be needed to address the specific information needs of any given program. It should be noted that the leading indicators are also envisioned as suitable to commercial endeavors.

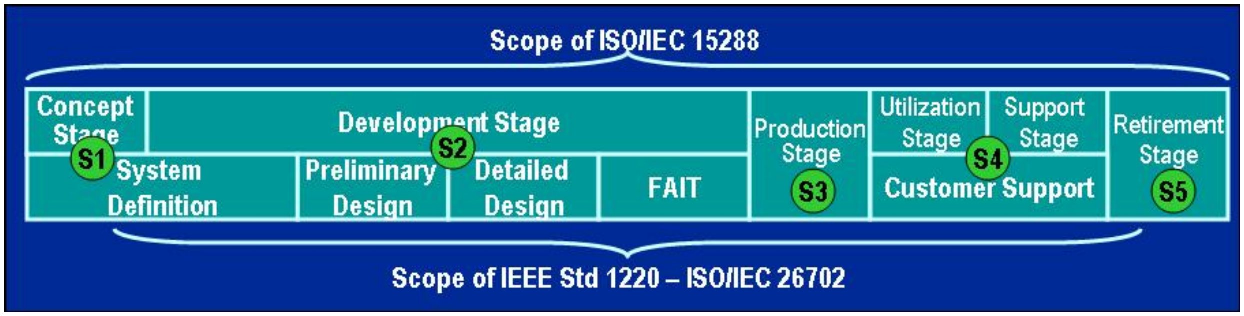


Figure 2 - ISO/IEC 15288, IEEE 1220 and ISO/IEC 26702 Stages

Figure 2 - ISO/IEC 15288, IEEE 1220 and ISO/IEC 26702 Stages, depict the same process and life cycle concepts in non-DoD terms. As demonstrated in Table 1, most of the leading indicators are trend measures that have broad applicability across both defense and commercial life cycle phases/stages. The DoD life cycle phases are denoted as P1 through P5 in Table 1 and are numbered as squares 1-5 in Figure 1. The industry standard life cycle stages are denoted as S1 through S5 in both Table 1 and Figure 2.

What is an example of how leading indicators have contributed to effective systems engineering on a program? A good example of the positive impact of using leading indicators was demonstrated within one of the pilots of the beta release guide. By monitoring the requirements validation and volatility trends, the pilot program team was able to more effectively predict readiness for the System Requirements Review (SRR) milestone. Initially the program had selected a calendar date to conduct the SRR, but in subsequent planning made the decision to have the SRR be event driven, resulting in a new date for the review wherein there could be a successful review outcome. That is, the review date was set based on an acceptable level of requirements validation and volatility in accordance with the leading indicators. Had the original calendar date been used, it is likely that the SRR would not have been successful and would have had to be repeated. See example Requirements Volatility graphic in Section 3.1.

Are the Leading Indicators Applicable to System of Systems Programs? The leading indicators have primarily been derived from experience on traditional systems engineering programs, however potential for use on System of Systems (SoS) programs has been given some consideration. First of all, some of the leading indicators are directly usable by a prime contractor as indicators for SoS level engineering activities. As SoS programs apply many of the same skills and perform many of the same activities as systems programs, the leading indicators do still apply. It is anticipated that in the SoS case, the interpretation of the leading indicators may involve some additional and/or unique considerations. For example how leading indicators, applied at the constituent systems level of a SoS, could be used effectively as a collected set of indicators and/or as aggregated indicators.

How will the Leading Indicators be Further Validated? The further validation efforts will be monitored by the core team, in collaboration with the participating collaboration organizations. Based on results of the program use, leading indicators will be adjusted as required. Additionally, recommendations will be developed regarding which leading indicators are most effective for particular types of programs.

What are the Plans for Improvement? In support of the continuing validation and refinement activity, industry and academic research is planned to analyze the effectiveness and adequacy of the measures in support of improved project performance. As lessons are learned in the continuing validation process, the core team will be providing briefings to and seeking input from selected government forums and systems engineering societies/associations. There are several activities planned for the future, including workshops on leading indicators involving cross discipline participation.

Table 1 - SYSTEMS ENGINEERING LEADING INDICATORS OVERVIEW

Leading Indicator	Insight Provided	Phases / Stages									
		P 1	P 2	P 3	P 4	P 5	S 1	S 2	S 3	S 4	S 5
Requirements Trends	Rate of maturity of the system definition against the plan. Additionally, characterizes the stability and completeness of the system requirements which could potentially impact design and production.	●	●	●	●	●	●	●	●	●	●
System Definition Change Backlog Trend	Change request backlog which, when excessive, could have adverse impact on the technical, cost and schedule baselines.			●	●	●		●	●	●	
Interface Trends	Interface specification closure against plan. Lack of timely closure could pose adverse impact to system architecture, design, implementation and/or V&V any of which could pose technical, cost and schedule impact.	●	●	●	●	●	●	●	●	●	
Requirements Validation Trends	Progress against plan in assuring that the customer requirements are valid and properly understood. Adverse trends would pose impacts to system design activity with corresponding impacts to technical, cost & schedule baselines and customer satisfaction.	●	●	●	●	●	●	●	●	●	
Requirements Verification Trends	Progress against plan in verifying that the design meets the specified requirements. Adverse trends would indicate inadequate design and rework that could impact technical, cost and schedule baselines. Also, potential adverse operational effectiveness of the system.	●	●	●	●	●	●	●	●	●	●
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.	●	●	●	●	●	●	●	●	●	●
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 Handling Trends	Effectiveness of the SE organization in implementing risk mitigation activities. If the SE organization is not retiring risk in a timely manner, additional resources can be allocated before additional problems are created.	●	●	●	●	●	●	●	●	●	●
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.		●	●	●	●		●	●	●	
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.			●				●			
Systems Engineering Staffing & Skills Trends	Ability of SE organization to execute total SE program as defined in the program SEP/SEMP. Includes quantity of SE personnel assigned, the skill and seniority mix and the time phasing of their application throughout the program lifecycle.	●	●	●	●	●	●	●	●	●	●
Process Compliance Trends	Quality and consistency of the project defined SE process as documented in SEP/SEMP. Poor/inconsistent SE processes and/or failure to adhere to SEP/SEMP, increase program risk.	●	●	●	●	●	●	●	●	●	●

3. LEADING INDICATOR DESCRIPTIONS

The following subsections provide a very brief description of the leading indicators, along with the leading insight provided by this indicator. The detailed description for each of the indicators is provided in Section 4, where each leading indicator has an associated *information measurement description*. For each leading indicator in Section 3, the reader should refer to the associated information in Section 4 in order to fully understand the leading indicator.

The format of the leading indicators information has been developed to be consistent with widely accepted measurement guidance in use in systems engineering and software organizations to include the references listed in Section 5.

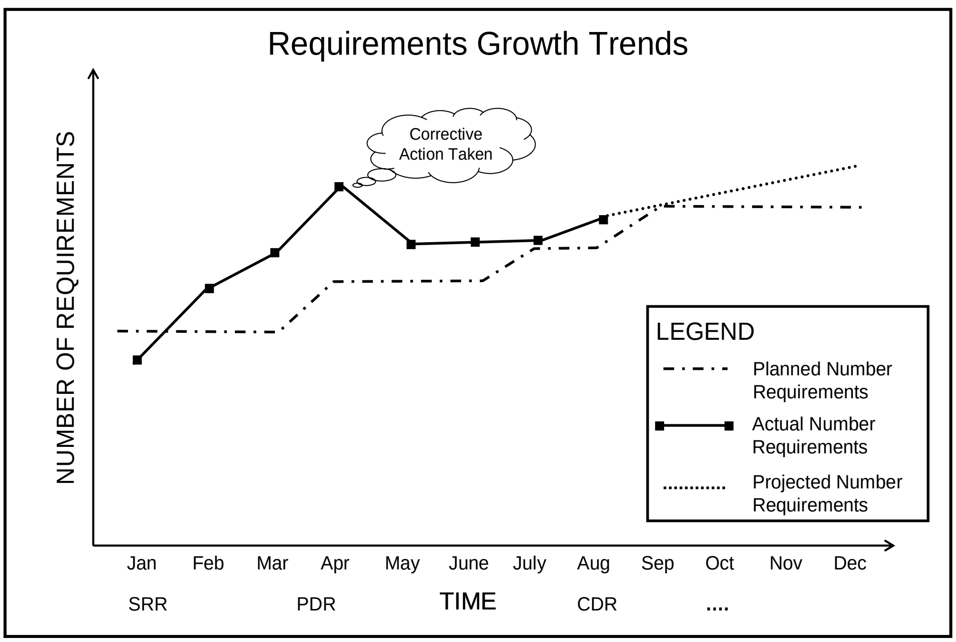
Important Note: *The graphics in this document are intended for basic illustrative purpose only, and may represent only one aspect of the overall indicator. These are prototype graphs and do not contain actual data. It is expected each organization will develop its own format for graphics. Underlying the information in the graphs, an organization will need to investigate root causes and related information to fully understand what is being flagged by the indicator.*

3.1. Requirements Trends

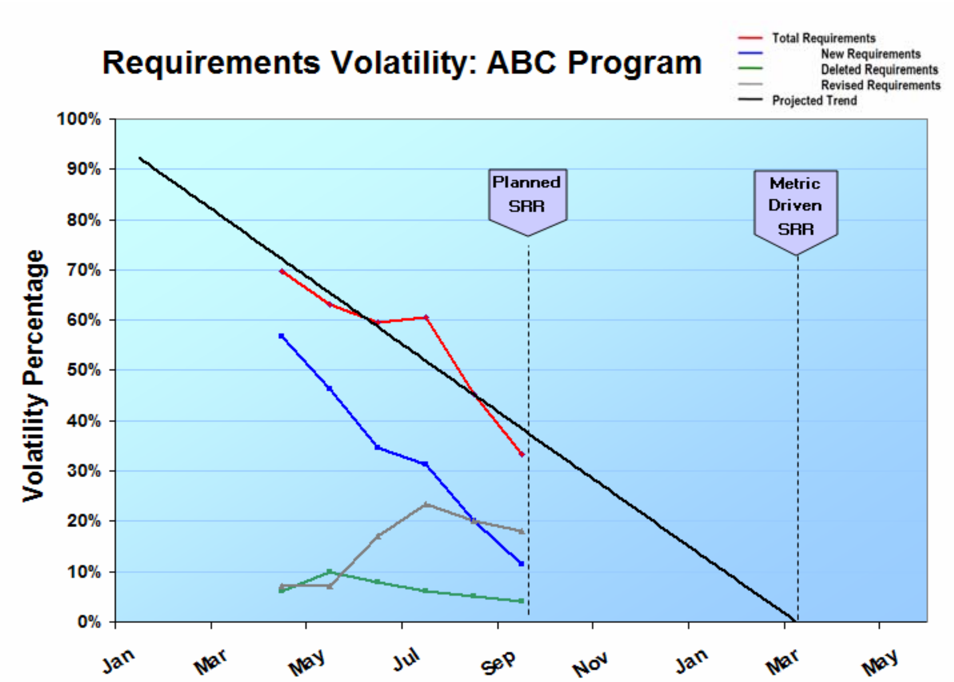
This indicator is used to evaluate the trends in the growth, change, completeness and correctness of the definition of the system requirements. This indicator provides insight into the rate of maturity of the system definition against the plan. Additionally, it characterizes the stability and completeness of the system requirements which could potentially impact design and production. 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.

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.1 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

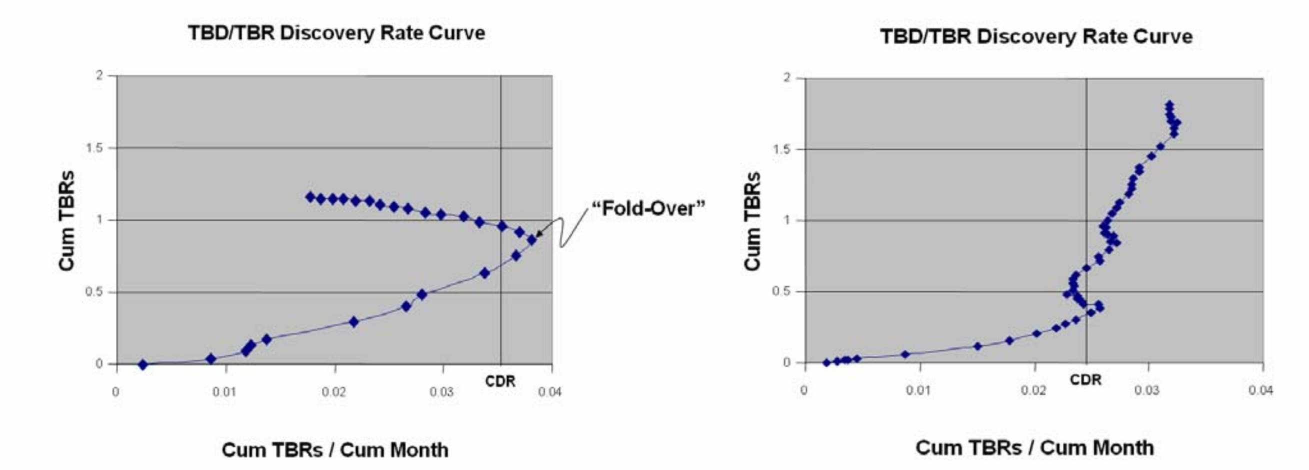
Requirements Trends



Requirements Trends. The graph illustrates growth trends in the number of requirements in respect to planned number of requirements (which is typically based on expected value based on historical information of similar projects as well as the nature of the program). Based on actual data, a projected number of requirements will also be shown on a graph. In this case, we can see around PDR that there is a significant variance in actual versus planned requirements, indicating a growing problem. An organization would then take corrective action – where we would expect to see the actual growth move back toward the planned subsequent to this point. The requirements growth is an indicator of potential impacts to cost, schedule, and complexity of the technical solution. It also indicates risks of change to and quality of architecture, design, implementation, verification, and validation.



Requirements Volatility. The graph illustrates the rate of change of requirements over time. It also provides a profile of the types of change (new, deleted, or revised) which allows root-cause analysis of the change drivers. By monitoring the requirements volatility trend, the program team is able to predict the readiness for the System Requirements Review (SRR) milestone. In this example, the program team initially selected a calendar date to conduct the SRR, but in subsequent planning made the decision to have the SRR be event driven, resulting in a new date for the review wherein there could be a successful review outcome.

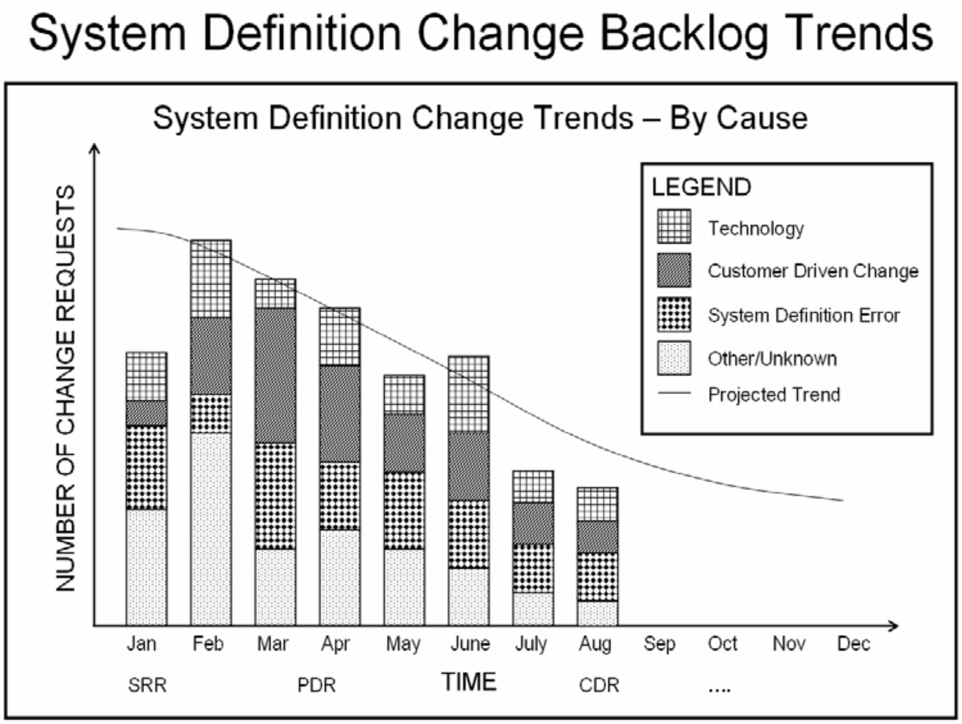


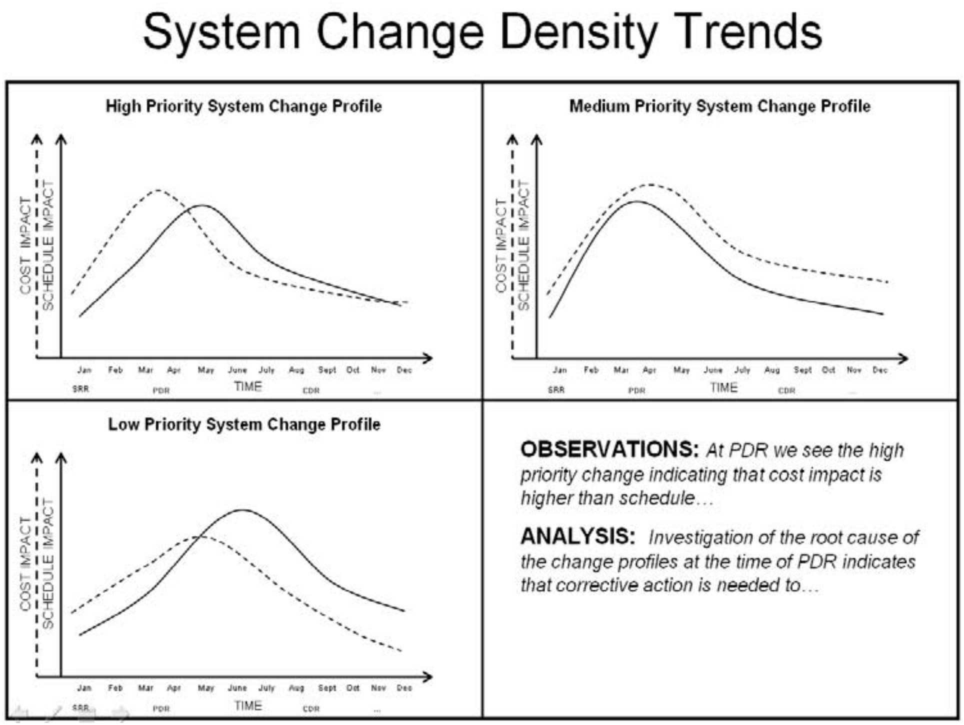
TBD/TBR Discovery Rate. The graphs show the cumulative requirement TBDs/TBRs vs. the ratio of cumulative TBDs/TBRs over cumulative time. The plot provides an indication of the convergence and stability of the TBDs/TBRs over the life cycle of the project. The graph on the left shows a desirable trend of requirement TBD/TBR stability; as the ratio of decreases and the cumulative number of TBDs/TBRs approaches a constant level. This "fold-over" pattern is the desirable trend to look for, especially in the later stages of project life cycle. In contrast, the graph on the right shows an increasing number of TBDs/TBRs even as the program approaches later stages of its life cycle; this is a worrisome trend in system design stability. An advantage of this plot is that, by shape of the graph (without having to read into the quantitative values), one can get a definitive idea for the trend of requirement stability, particularly when it is associated with certain key program milestones. The similar graphing technique can be applied to TBDs/TBRs in the Interface Trends indicator and to the number of Requests for Change (RFCs) measure for the System Definition Change Backlog Trends indicator.

3.2. System Definition Change Backlog Trends

This indicator is used to evaluate the trends in system definition change backlog, indicating whether the change backlog is impeding system definition progress or system development quality/schedule. It may also provide an indication of potential rework due to changes not being available in a timely manner.

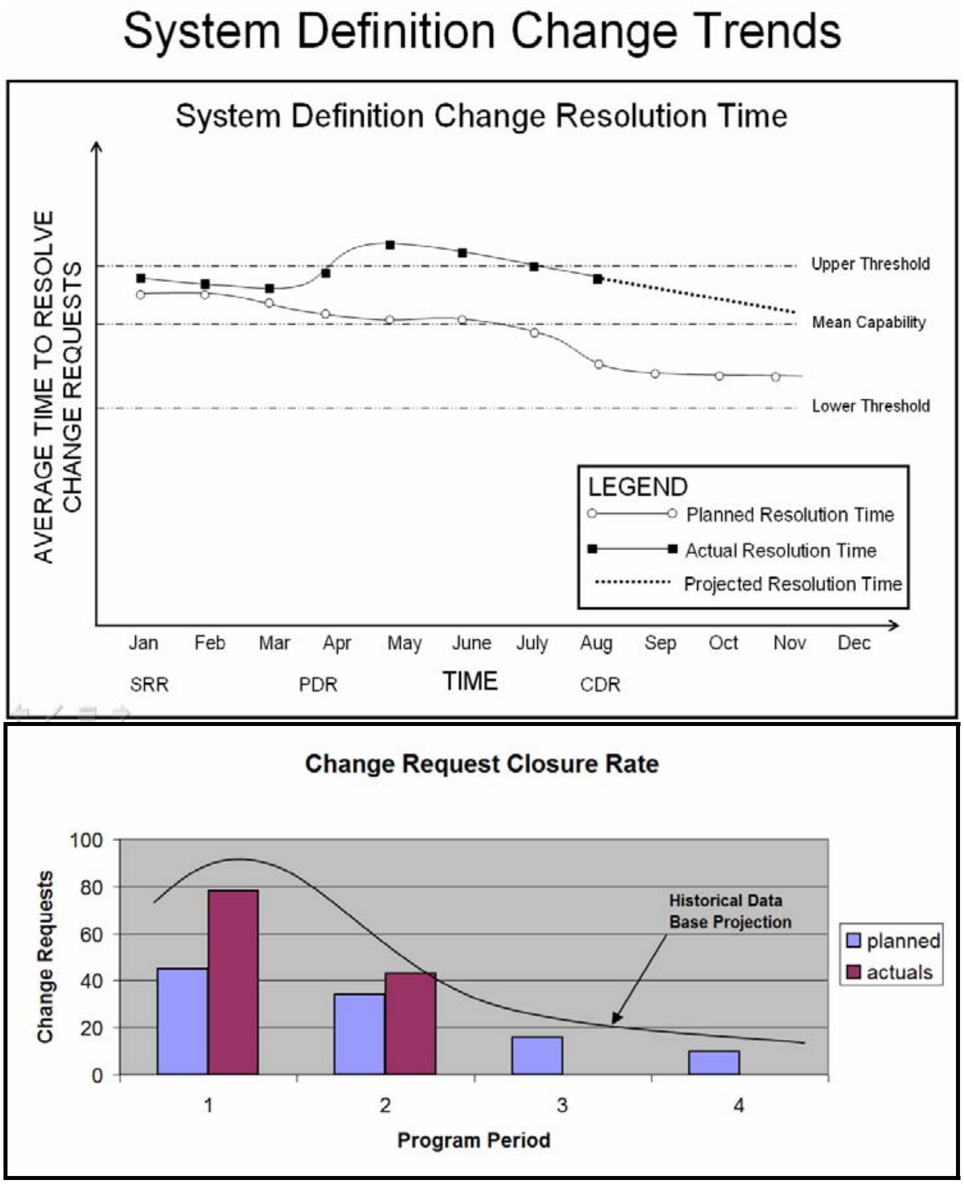
An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.2 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.





System Definition Change Backlog Trends. The graphs included here illustrate the system definition change trend in respect to the historically based expected trend of changes. In the case of the System Definition Change Trend – By Cause example, we see at SRR there are actually less changes than expected, and the program might need to investigate the factors for this to determine if this is a concern, and perhaps may lead to higher levels of change later in the program. The number of Change Requests in the month following the SRR, could project to a very challenging trend, but generally falls within historical experience. Fortunately, the trend observed between the SRR and the PDR tracks remains in line with historical experience, perhaps suggesting that no significant issues exist with respect to the total number of changes. The organization may find it useful investigate the individual trends associated with the changes categorized according to cause. A very mature organization might have expected trend lines for each type of change.

In the case of the System Change Density Trend example, we see that this indicator is used to evaluate the changes categorized according to priority over time in terms of cost and schedule impact. It indicates whether the program is effectively managing the program changes as shown by predicted impact ratings over time. If the impacts continue to grow or not be reduced, the customer satisfaction may be negatively impacted due to resulting cost, schedule, or technical impacts. In addition to the change data itself, the average time to resolve the change requests provides additional leading information, as shown in the example graphs below.



The System Definition Change Resolution Time graph illustrates the average time to resolve change requests versus what is planned for the program or historical data. Based on historical data and nature of the program, a projection is made for the future; In this case, the actual data depicted through Program Period 2 warrants further analysis as it is significantly over the expectations (it is neither to program plan or historical-based projects) and may not be trending appropriately over time. Mature organizations should be able to identify lower and upper thresholds, as well as average time (organization's mean capability), to resolve a change. The Change Request Closure Rate graphs illustrates the number of change requests resolved versus what is planned for the program based on historical data and nature of the program. Based on actual data to date, a projection is made for the future.

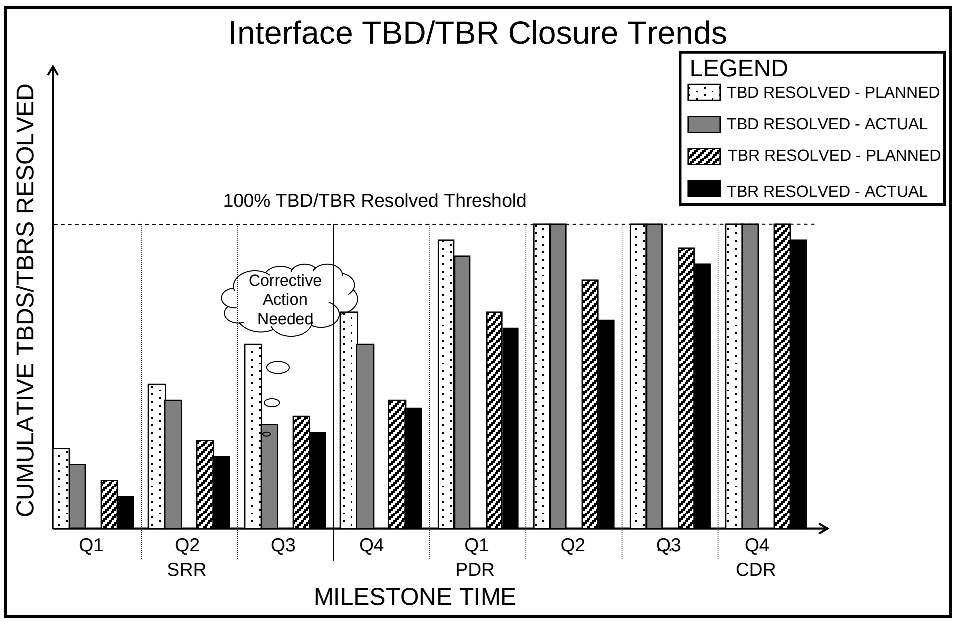
The graph used for the Requirement TBD/TBR Discovery Rate in Section 3.1 can also be applied to plot the Request for Changes (RFCs) to indicate the trend for system definition and design stability.

3.3. Interface Trends

This indicator is used to evaluate the trends related to growth, change, completeness, and correctness of the definition of system interfaces. This indicator 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.

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.3 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practice.

Interface Trends



Interface TBD/TBR Closure Trends. The graph illustrates the actual cumulative number of TBDs and TBRs that have been resolved compared to what is planned to be resolved based on historical data and expectations given the program characteristics. It can be seen that in Q3 after SRR, the actual TBDs are significantly lower than planned and corrective action is then taken.

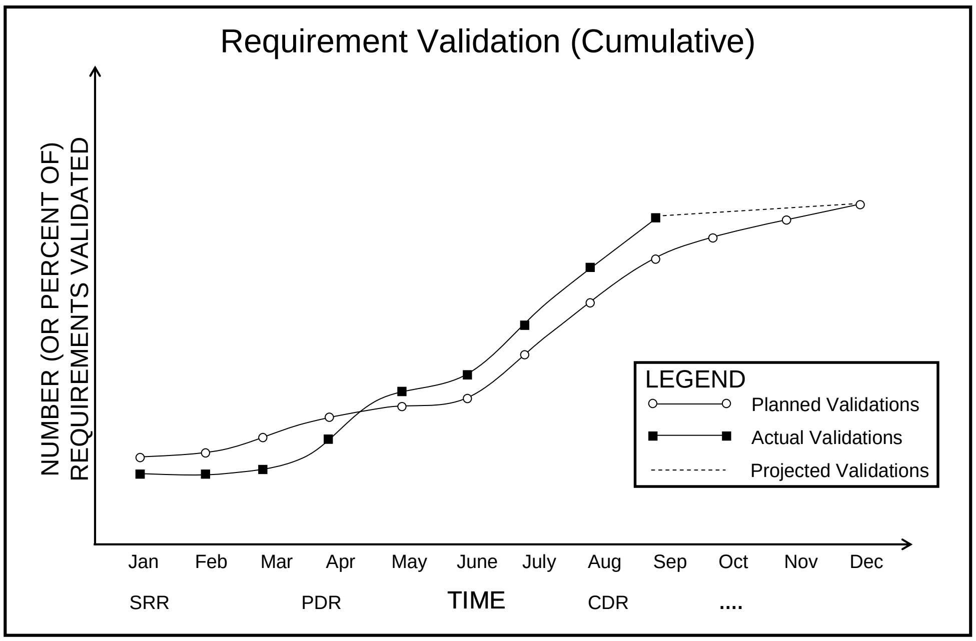
The graph used for the Requirement TBD/TBR Discovery Rate in Section 3.1 can also be applied to plot the Interface TBD/TBR trends to indicate the trend for system interface definition and design stability.

3.4. Requirements Validation Trends

This indicator is used to evaluate the trends in the rate and progress of requirements validation activity. It provides early insight into the level of understanding of customer/user needs. It indicates risk to system definition due to inadequate understanding of the customer/user needs. It may also indicate risk of schedule/cost overruns, post delivery changes, or user dissatisfaction

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.4 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

Requirements Validation Trends



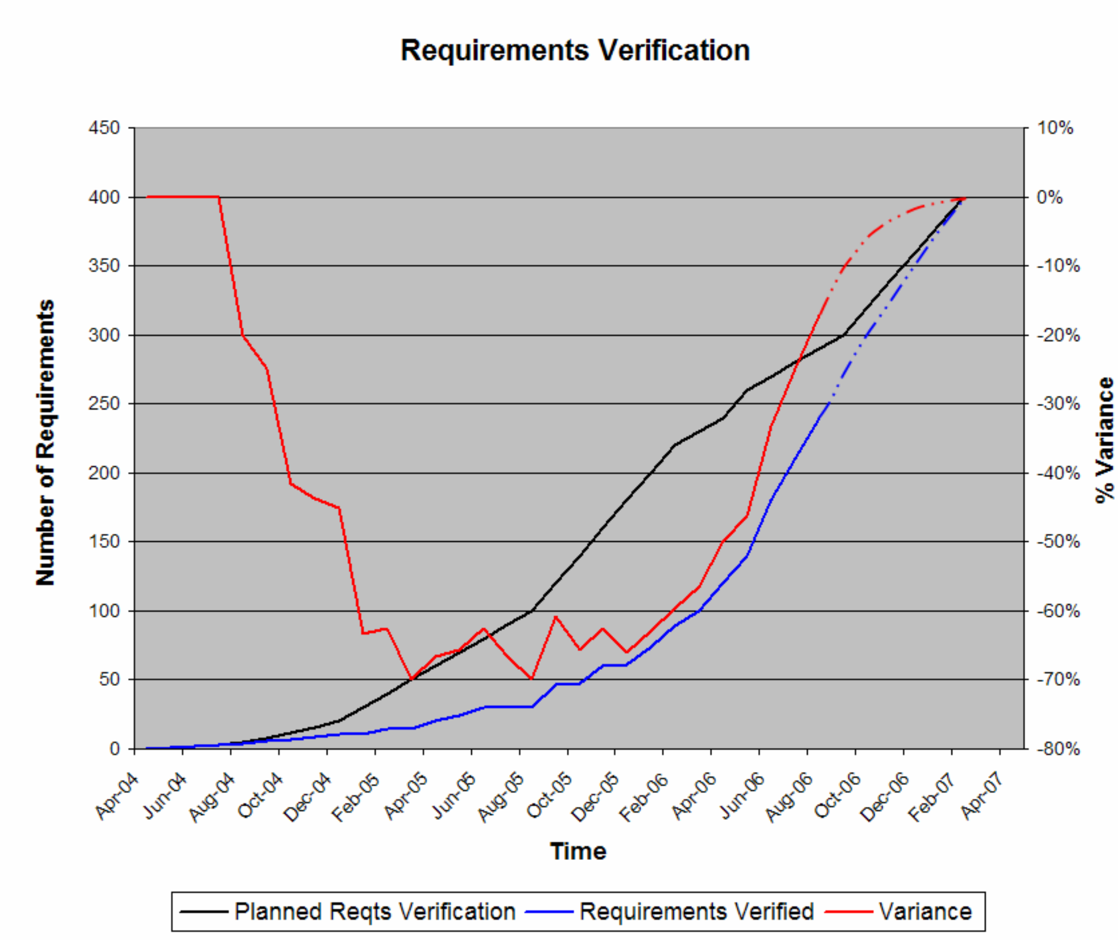
Requirements Validation Trends. The graph illustrates the actual number of (or it could also be shown as the percent of) requirements validated versus the planned validation based on historical data and the nature of the project. A projection will also be made based on the actual validation trend. In this case, we see at CDR that the actual validated requirements in higher than planned, indicating that the validation activity is on track.

3.5. Requirements Verification Trends

This indicator is used to evaluate the trends in the rate and progress of requirements verification. It provides early insight into the ability to meet customer/user requirements. The measure indicates possible risk to system definition due to inadequate ability to meet the customer/user requirements. It may indicate risk of schedule/cost overruns, potential for post delivery post delivery changes, or customer/user dissatisfaction.

An example of how such an indicator might be reported would be similar to the graph shown for requirements validation (see section 3.4).

Refer to the measurement information specification in Section 4.5 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

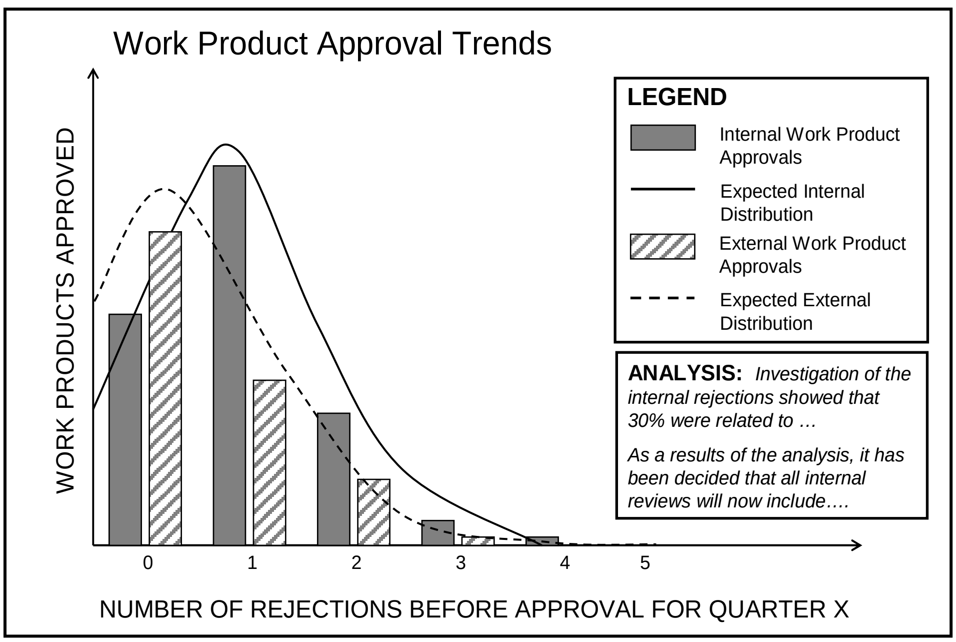


3.6. Work Product Approval Trends

This indicator is used to evaluate the trends in the internal and external approvals of work products. It may indicate a problem with identification of needs or transformation into requirements/design. It may also indicate that the end product is not of high enough quality and may result in rework or need for changes in plan. It may also be the case that the review process definition or implementation may be inadequate. On the positive side, the measure will indicate readiness for entry into review milestones.

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.6 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

Work Product Approval Trends



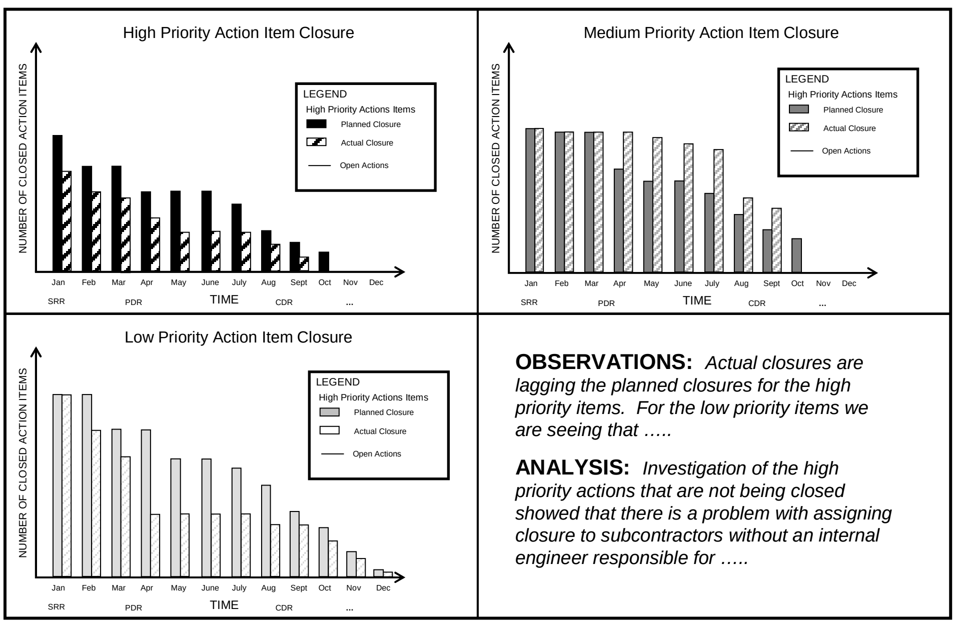
Work Product Approval Trends. The graph illustrates success of the work product approvals for Quarter X in respect to how many rejections there were for work products before approval for both internal work product approvals and external work product approvals. Actual rejections are shown with an overlay of the expected internal and external approvals based on historical data and the nature of the project. Analysis will be needed to understand why rejections are happening, and the graphic could include a breakdown of the root causes as stacked bars, for example, rather than just the single bar. Additionally, it may be helpful to use a quad-chart or other graphical presentation techniques to look at performance on related work products together.

3.7. Review Action Closure Trends

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

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.7 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

Review Action Item Closure Trends



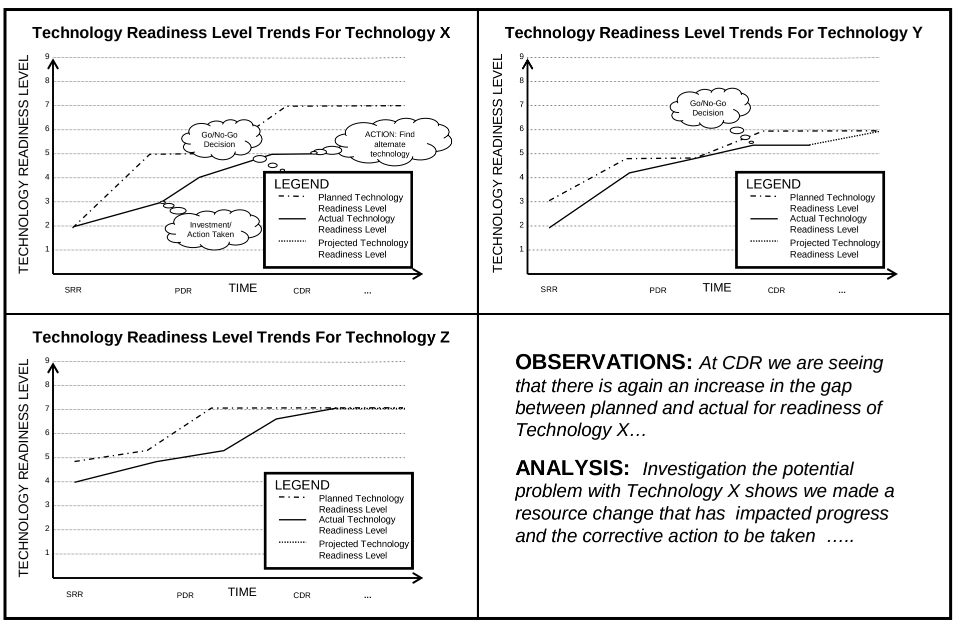
Review Action Item Closure Trends. The graph illustrates the number of review action items that are closed in each month, in respect to the number that is planned for closure in that month, based on historical information and nature of the project. The graphic shows the high priority, medium priority, and low priority actions on separate quadrants. A measurement analyst would be able to make observations that would require additional detailed analysis to decide if corrective action was required, and the nature of such action.

3.8. Technology Maturity Trends

This indicator is used to evaluate the trends in technology maturity trends, including readiness and obsolescence, of specific technologies that are under development. The measure may indicate that technology opportunities exist that need to be examined and may warrant product changes. It may also indicate when a technology is becoming obsolete and may be a candidate for replacement. Trend of obsolescence exposure gives an indication of when to take action due to obsolescence risk. This should help avoid surprises from obsolescence and plan for right timing of technology insertion of new technologies

An example of how such an indicator might be reported is show below for the readiness trends for selected technologies. Refer to the measurement information specification in Section 4.8 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

Technology Maturity Trends



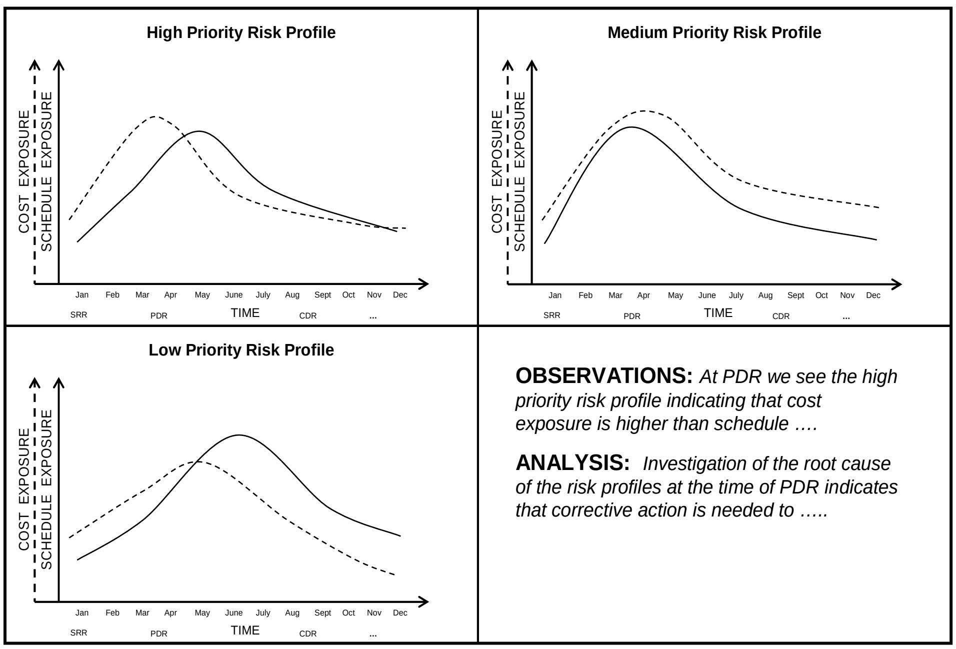
Technology Readiness Trends. The graph illustrates the actual readiness level of each of three technologies (X, Y, Z) in respect to the planned readiness level. The planned readiness would be determined by factors such as technology investment, availability of component technologies, and other factors. Observations are made on the graphs, with further analysis needed to understand underlying issues and causes where a potential problem is seen. For example, for Technology X, we see that just prior to PDR that there is a significant gap in the actual versus planned readiness, and that additional investment action was taken which post PDR brought the actual readiness much closer to planned, allowing for a go/no-go decision.

3.9. Risk Exposure Trends

This indicator is used to evaluate the risk exposure over time in terms of cost and schedule, and in context of the level of risk. It indicates whether the program is effectively managing the program risks as shown by predicted exposure ratings over time. If the risk exposure continues to grow or not be reduced, the customer satisfaction will be negatively impacted due to resulting cost, schedule, or technical impacts. It is recommended the Risk Exposure Trends indicators be used in conjunction with the Risk Handling Trends indicators as discussed in section 3.10.

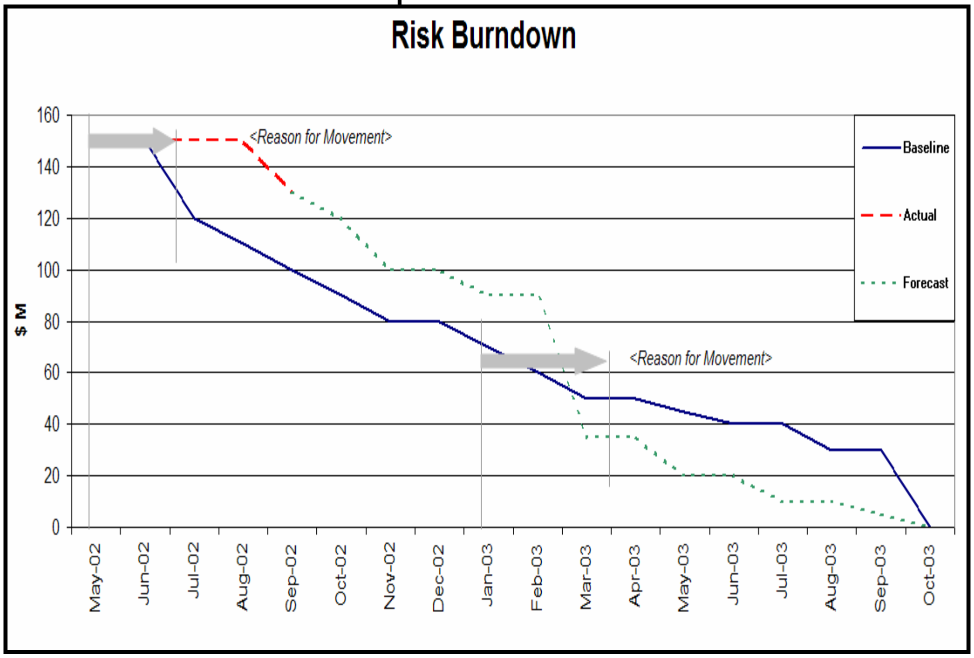
An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.9 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

Risk Exposure Trends



Risk Exposure Trends. The graph illustrates risk profiles of the program in regard to cost and schedule exposure over the life cycle. In this case, profiles for high, medium, and low priority risks are shown separately. The analyst can make certain observations which will require additional analysis to understand what the graphic is showing. For illustrative purposes, cost and schedule exposures are included in this graph. While not included, technical exposure would be another element of this indicator.

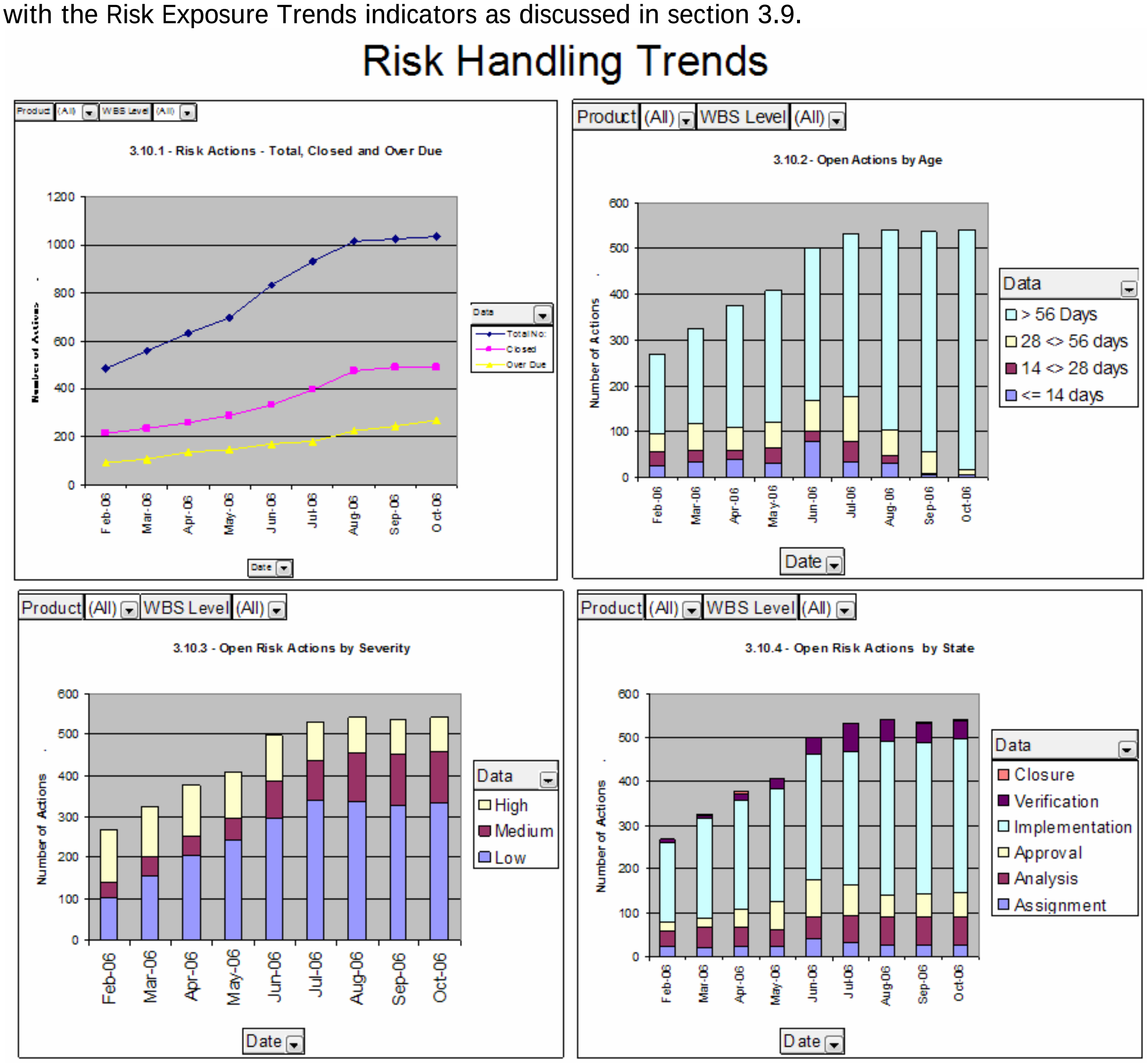
Risk Exposure Trends



Risk Burndown. 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 program team projected the burndown for the remainder of the program to identify whether the risk exposure could be reduced to an acceptable level as the program proceeds and where there were realistic opportunities that could significantly reduce the exposure. To build confidence in the projection, the program team needed to determine the reason for any significant movement (positive or negative). The first movement was due to late program ramp-up and requirements changes. The second movement was where the program team would be able to insert technology to eliminate a set of risks.

3.10. Risk Handling Trends

This indicator is used to evaluate effectiveness of handling risks. It indicates whether the program is proactively handling/treating potential problems or risks at the appropriate times in order to minimize or eliminate their occurrence and impacts to the program. If the actions are not closing per plan, then there is a higher probability that risks will be realized. This insight can identify where additional action may be needed to avoid preventable problems or reduce impacts. This indicator may also identify that the program does not have an iterative or continuous process implementation for risk management. Thus, new risks may not be identified and handled, and may affect the program and technical effectiveness/success. Refer to the measurement information specification in Section 4.10 for details regarding the indicator. It is recommended the Risk Handling Trends indicators be used in conjunction with the Risk Exposure Trends indicators as discussed in section 3.9.

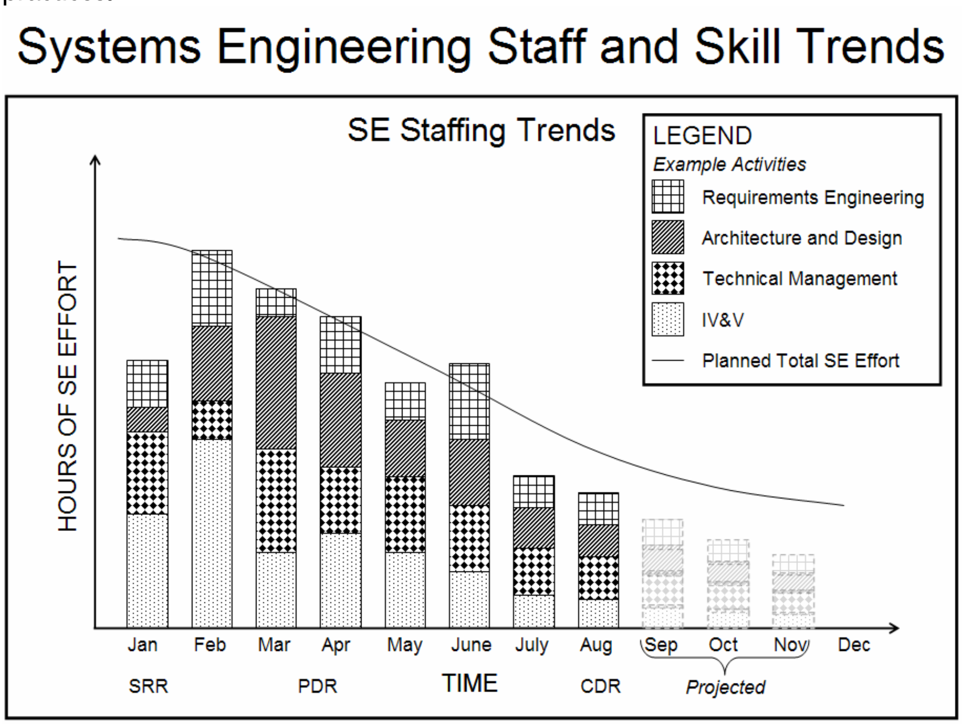


Risk Handling Trends. As an example of appropriate analysis, consider these four related risk handling trends as a group. Indicator 3.10.1 Risk Actions, broadly shows that the project is not closing the actions items and also the number of over due actions are increasing. Indicator 3.10.2 Open Actions by Age, shows risk actions beyond set acceptable thresholds. Indicator 3.10.3 Open Risk Actions by Severity, might temper any anxiety given the fact that the majority of the actions are of a low and medium severity. Finally, Indicator 3.10.4 Open Risk Actions by State, gives an understanding that the risk management process is being followed in that the majority of actions are being implemented.

3.11. Systems Engineering Staffing and Skills Trends

This indicator is used to evaluate the staffing and skills mix trends in accordance with plans and expectations. It indicates whether the expected level of SE effort, staffing, and skill mix is being applied throughout the life cycle based on historical norms for successful projects and plans. It may also indicate a gap or shortfall of effort, skills, or experience that may lead to inadequate or late SE outcomes. The planned staffing can be compared to projected availability through the life cycle to provide an earlier indication of potential risks. It is also a necessary contributor to staff related cost estimates.

An example of how such an indicator might be reported is show below. Refer to the measurement information specification in Section 4.11 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.



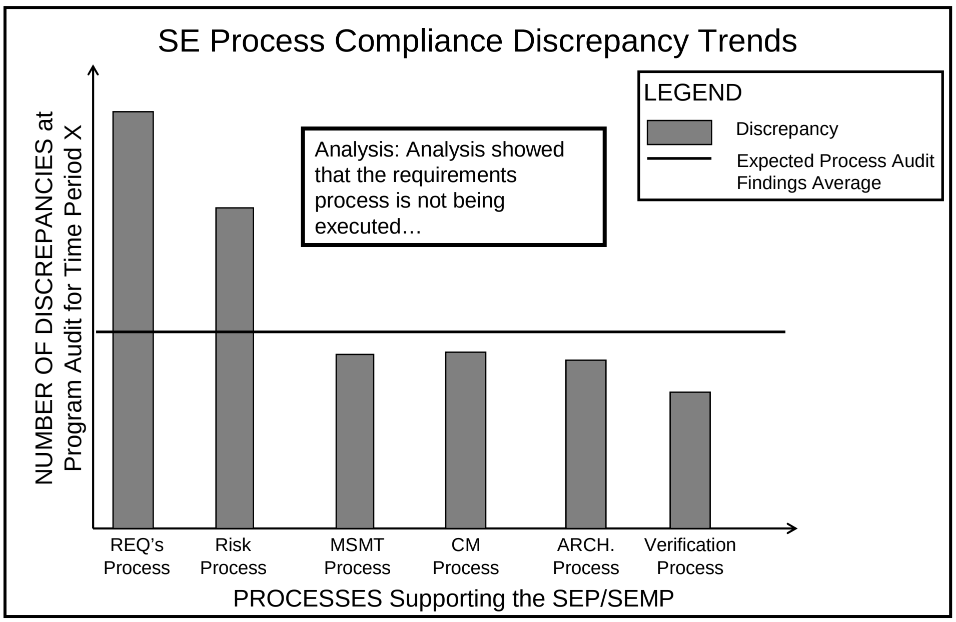
Systems Engineering Staffing Trends. The graph illustrates the systems engineering effort versus the planned effort based on historical data and nature of the project. In this graph, the effort is shown in regard to categories of systems engineering activities. We can see that at SRR the data would have shown that the actual effort was well below the planned effort, and that corrective action must have been taken to align actual with planned in the next month of the project.

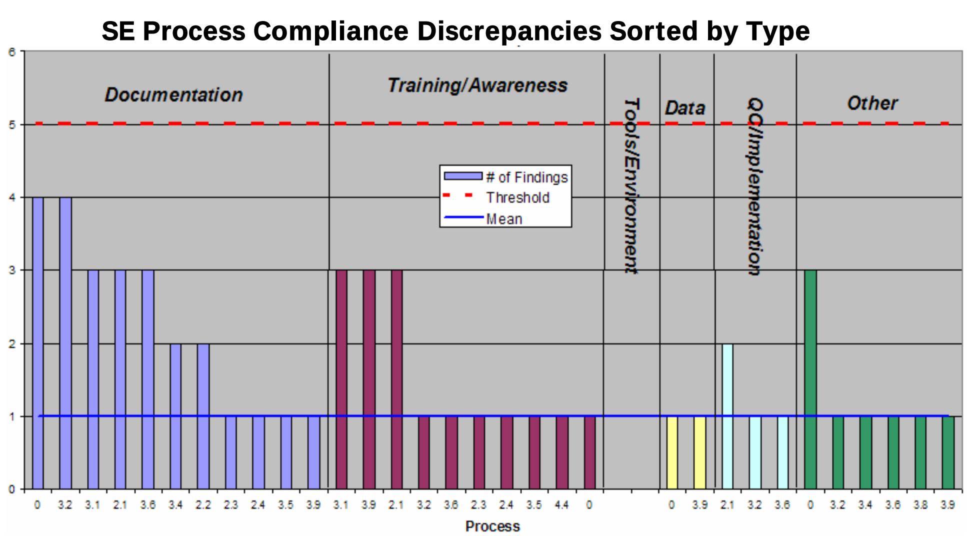
3.12. *Process Compliance Trends*

This indicator is used to evaluate the trends in process compliance discrepancies to ensure that the program is within expected range for process compliance. It indicates where process performance may impact other processes, disciplines, or outcomes of the project. General non-compliance indicates increased risk in ongoing process performance and potential increases in variance. Non-compliance of individual processes indicates a risk to downstream processes.

An example of how such an indicator might be reported is shown below. Refer to the measurement information specification in Section 4.12 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.

SE Process Compliance Trends



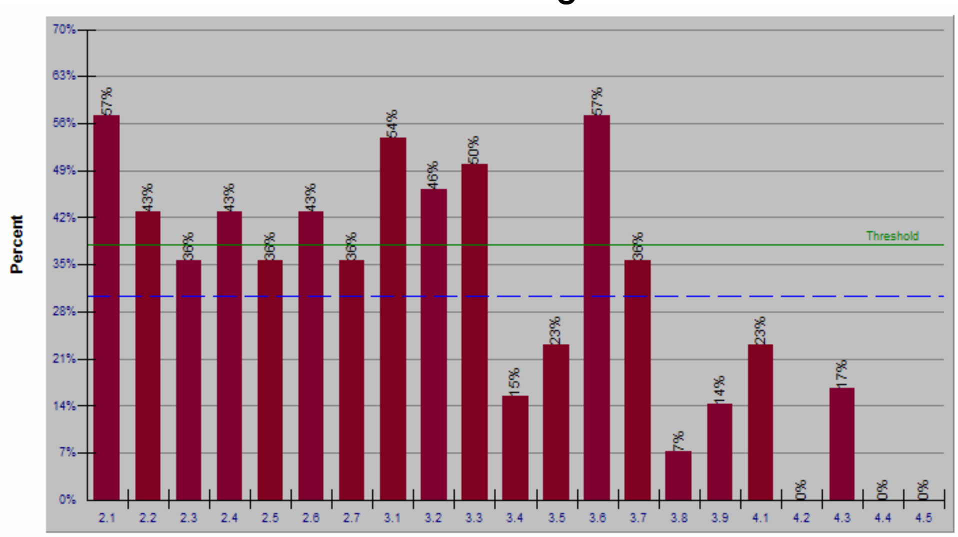


Note: The numbers on the horizontal axis of this figure represent the program processes.

Systems Engineering Process Compliance Trends. The Process Compliance Discrepancy Trends graph illustrates the number of discrepancies for each major process or process area, along with the expected process audit findings based on historical program or organizational audit information. In this case, it can be seen that there are indications that there are issues with the requirements process and the risk process. Further investigation will be needed to determine the root causes – it could be that processes are not being followed, but there could also be cases where there are opportunities for improvement of the process that are needed. As is done in the second figure, it is often useful to sort the discrepancies by type or cause of the discrepancy. In this case, the largest number of discrepancies are caused by issues with the documentation. Issues with the training or lack of awareness of the processes is the next major source of discrepancies in this example. These issues with the documentation or training reflect opportunities for the program or organization to make improvements that will eliminate the risk of errors in future SE performance. The number of discrepancies can give an indication of process performance strength or weakness, helping the program or organization to prioritize improvement efforts.

The Process Tailoring Trend graph, below, depicts the amount of tailoring per process. The numbers on the x-axis of the graph are numerical process identifiers. The graph shows a percentage representing the degree of tailoring for each process by the set of programs in the organization. Furthermore, thresholds are set for the acceptable amount of tailoring before needing to investigate whether the needs with respect to the process have shifted. This could be depicted by threshold lines or color-coding. For example, within the acceptable range is depicted in green and exceeding the acceptable range is red. These thresholds might indicate further investigation is needed to determine if there is a systemic problem: a significant program specific process change might indicate the need to update standard process materials or conversely that the specific program will likely have a great deal of difficulty operating within the standard business processes and the accompanying culture.

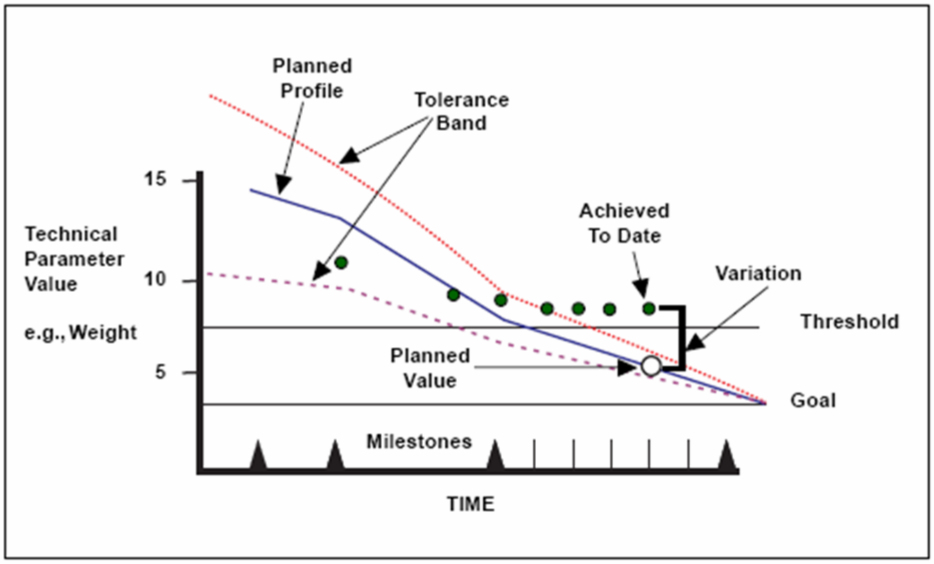
Process Tailoring Trends



3.13. Technical Measurement Trends

This indicator is used to evaluate the trends in progress toward achieving technical performance requirements. It aids in understanding the risk, progress, and projections regarding a system element or system of interest achieving the critical technical performance requirements.

Refer to the measurement information specification in Section 4.13 for the details regarding this indicator; the specification includes the general information which would be tailored by each organization to suit its needs and organizational practices.



Technical Performance Measure is defined well by the figure above (based on Figure 14.-2 Technical Performance Measurement – The Concept - from Defense Acquisition University's System Engineering Fundamentals). Measured values that fall outside established decision criteria (tolerance bands) alert management to take action or perform further investigation. Other relevant terms and relationships are defined as follows:

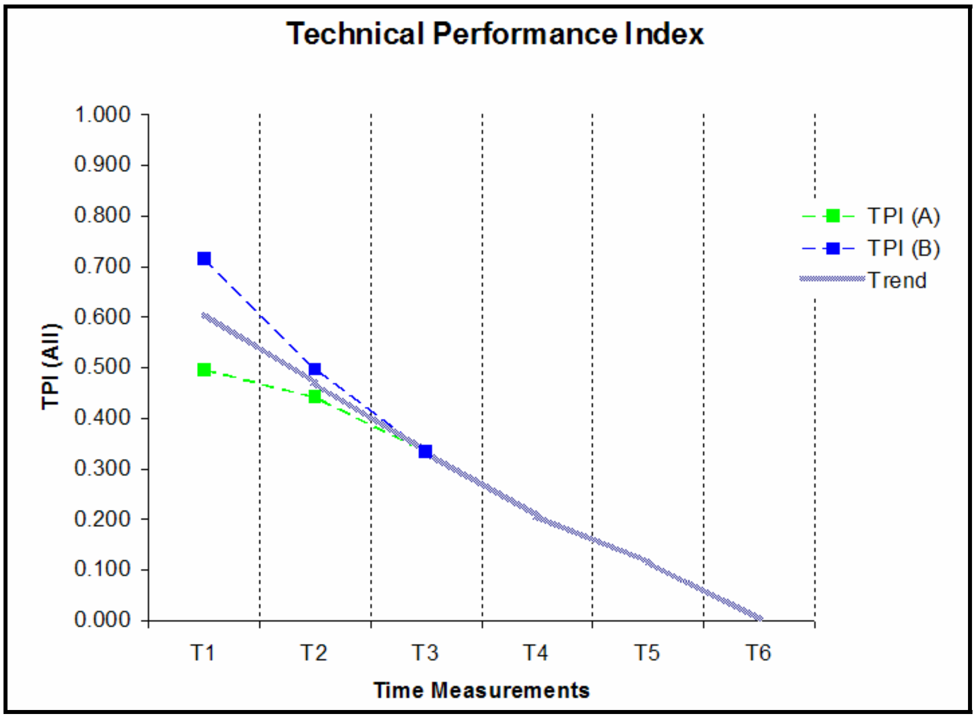
- Achieved-to-Date - Measured technical progress or estimate of progress plotted and compared with the planned progress at designated milestone dates.
- Planned Value - Predicted value of the technical parameter for the time of measurement based on the planned profile.
- Planned Profile - Profile representing the projected time-phased demonstration of a technical parameter requirement. It describes the underlying model of expected behavior of the measures over time.
- Tolerance Band - Management alert limits placed on each side of the planned profile to indicate the envelope or degree of variation allowed. The criteria are used to trigger action or further investigation. Tolerance bands are an acknowledgement of estimating error and reflect acceptable risk limits associated with achieving the performance measured by the TPM.
  - Threshold - The limiting acceptable value of a technical parameter; usually a contractual performance requirement.
- Demonstrated Technical Variance – the difference between the 'Planned Value' and the 'Achieved-to-Date' (or demonstrated/measured) value at a specific point in time.
- Predicted Technical Variance – the difference between the 'Planned Value' at EOC and the 'Current Estimate' of the parameter.

Technical Performance Measures

				Current						
Technical Performance Measures	TPM 1	G	G	G	Y	Y	Y	G	G	G
	TPM 2	G	G	G	G	G	G	G	G	G
	TPM 3	G	G	R	R	R	R	Y	Y	Y
	TPM 4	G	G	G	G	G	G	G	G	G
	TPM 5	G	Y	Y	Y	Y	Y	G	G	G
	TPM 6	G	Y	Y	Y	G	G	G	G	G
	TPM 7	G	Y	Y	G	G	G	G	G	G
	TPM 8	G	Y	Y	G	G	G	G	G	G
	TPM 9	G	Y	R	R	R	R	R	Y	Y

Time

The technical performance measures table depicts a programs key or critical TPMs, and the status of these measures over time. The trend is the number of key or critical TPMs in each status color Red, Yellow, or Green as declared by the program. The important requirement is that the criterion for the status of the TPMs is standardized by the business.



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

The index has successfully enabled discussions of programmatic technical issues, by appropriately simplifying the program details for non-technical settings while still retaining the ability to drill-down to lower tiered levels to understand problem areas with trend data. Furthermore, the TPIs depict the program trend for achieving overall technical performance parameters and the extent of performance lag. This aids in the identification of the risk-driving TPMs and in the program prioritization of focus to improve technical performance.

4. INFORMATION MEASUREMENT SPECIFICATIONS

The following subsections provide the details of the leading indicators. The brief description for each of the indicators is provided in Section 3. For each leading indicator in described in Section 3, the reader will find the associated information in order to fully understand the leading indicator, in Section 4.

The table below describes the typical anatomy of the information measurement specification. The format of each leading indicators specification follows.

{Name of Leading Indicator}	
Information Need Description	
Information Need	*Specifies what the information need is that drives why we need this leading indicator to make decisions*
Information Category	*Specifies what categories (as defined in the PSM) are applicable for this leading indicator (for example, schedule and progress, resources and cost, product size and stability, product quality, process performance, technology effectiveness, and customer satisfaction)*
Measurable Concept and Leading Insight	
Measurable Concept	*Defines specifically what is measurable*
Leading Insight Provided	*Specifies what specific insights that the leading indicator may provide in context of the measurable concept - typically a list of several or more*
Base Measure Specification	
Base Measures	*A list of the base measures that are used to compute one or more leading indicators - a base measure is a single attribute defined by a specified measurement method*
Measurement Methods	*For each base measure, describes the method used to count the base measure, for example simple counting or counting then normalized*
Unit of Measurement	*Describes the unit of measure for each of the base measures*
Entities and Attributes	
Relevant Entities	*Describes one or more particular entities relevant for this indicator – the object is to be measured (for example, requirement or interface)*
Attributes	*Lists the subset of particular attributes (characteristics or properties) for each entity that are of interest for this leading indicator*
Derived Measure Specification	
Derived Measure	*Describes one or more measures that may be derived from base measures that will be used individually or in combination as leading indicators*
Measurement Function	*The function for computing the derived measure from the base measures*
Indicator Specification	
Indicator Description and Sample **See 3.3**	*A detailed specific description and display of the leading indicator, including what base and/or derived measures are used*
Thresholds and Outliers	*Would describe thresholds and outliers for the indicator; this information would be company (and possibly program) specific*
Decision Criteria	*Provides basic guidance for triggers for investigation and when possible action to be taken*

{Name of Leading Indicator}	
Indicator Interpretation	*Provides some insight into how the indicator should be interpreted; each organization would be expected to tailor this*
Additional Information	
Related Processes	*Lists related processes and sub-processes*
Assumptions	*Lists assumptions for the leading indicator to be used, for example, that a requirements database is maintained*
Additional Analysis Guidance	*Any additional guidance on implementing or using the indicators*
Implementation Considerations	*Considerations on how to implement the indicator (assume this expands with use by organization)*
User of Information	*Lists the role(s) that use the leading indicator information*
Data Collection Procedure	*Details the procedure for data collection*
Data Analysis Procedure	*Details the procedure for analyzing the data prior to interpretation*

4.1. Requirements Trends

<table>
<tr><th colspan="2">Requirements Trends</th></tr>
<tr><th colspan="2">Information Need Description</th></tr>
<tr><td>Information Need</td><td>• Evaluate the stability and adequacy of the requirements 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 requirements.</td></tr>
<tr><td>Information Category</td><td>1. Product size and stability – Functional Size and Stability
2. Also may relate to Product Quality and Process Performance (relative to effectiveness and efficiency of validation)</td></tr>
<tr><th colspan="2">Measurable Concept and Leading Insight</th></tr>
<tr><td>Measurable Concept</td><td>Is the SE effort driving towards stability in the System definition (and size)?</td></tr>
<tr><td>Leading Insight Provided</td><td>• Indicates whether the system definition is maturing as expected.
• Indicates risks of change to and quality of architecture, design, implementation, verification, and validation.
• Indicates schedule and cost risks.
• Greater requirements growth, changes, or impacts than planned or lower closure rate of TBDs/TBRs than planned indicate these risks.
• May indicate future need for different level or type of resources/skills.</td></tr>
<tr><th colspan="2">Base Measure Specification</th></tr>
<tr><td>Base Measures</td><td>1. # Requirements
2. # Requirement TBDs/TBRs (by selected categories: interval, milestone)
3. # Requirement defects (by selected categories; e.g., type, cause, severity)
4. # Requirements changes (by selected categories; e.g., type, cause)
5. Impact of each requirement change (in estimated effort hours or range of hours)
6. Start/complete times of change</td></tr>
<tr><td>Measurement Methods</td><td>1. Count the number of requirements
2. Count the number of requirements TBDs/TBRs
3. Count the number of requirements defects per category
4. Count the number of requirements changes per category
5. Estimate the effort hours or range of effort hours expected for each change.
6. Record from actual dates & times of requirements complete in the CM system</td></tr>
<tr><td>Unit of Measurement</td><td>1. Requirements
2. TBDs/TBRs
3. Defects
4. Changes
5. Effort Hours
6. Date and Time (Hours, Minutes)</td></tr>
<tr><th colspan="2">Entities and Attributes</th></tr>
<tr><td>Relevant Entities</td><td>• Requirements</td></tr>
<tr><td>Attributes</td><td>• Requirement TBDs/TBRs
• Requirement Defects
• Requirement Changes
• Time interval (e.g., monthly, quarterly, phase)</td></tr>
</table>

Requirements Trends

Derived Measure Specification

Derived Measure	1. % Requirements approved 2. % Requirements Growth 3. % TBDs/TBRs closure variance per plan 4. % Requirements Modified 5. Estimated Impact of Requirements Changes for time interval (in Effort hours) 6. Defect profile 7. Defect density 8. Defect leakage (or escapes) 9. Cycle time for requirement changes (each and average)
Measurement Function *	1. (# requirements approved / # requirements identified and defined)*100 as a function of time 2. ((# requirements in current baseline - # requirements in previous baseline) / (# requirements in previous baseline) * 100 3. ((# TBDs/TBRs planned for closure – # TBDs/TBRs closed) / # TBDs/TBRs planned for closure) * 100 4. (# Requirements modified / Total # requirements) * 100 as a function of time 5. Sum of estimated impacts for changes during defined time interval during defined time interval 6. Number of defects for each selected defect categorization 7. # of requirements defects / # of requirements as a function of time 8. Subset of defects found in a phase subsequent to its insertion 9. Elapsed time (difference between completion time and start times) or total effort hours for each change

Indicator Specification

Indicator Description and Sample **Also see 3.1**	Line or bar graphs that show trends of requirements growth and TBD/TBR closure per plan. Stacked bar graph that shows types, causes, and impact/severity of changes. Show thresholds of expected values based on experiential data. Show key events along the time axis of the graphs. 1. Line or bar graphs that show growth of requirements over time 2. Line or bar graphs that show % requirements approved over time 3. Line or bar graphs that show % TBDs/TBRs not closed per plan 4. Line or bar graphs that show % requirements modified, 5. Line or bar graphs that show estimated impact of changes for time interval (in effort hours) 6. Line or bar graphs that show defect profile (by types, causes, severity, etc.) 7. Line or bar graphs that show defect density 8. Stacked bar graph that shows types, causes, and impact/severity of changes on system design
Thresholds and Outliers	Organization dependent.
Decision Criteria	Investigate and, potentially, take corrective action when the requirements growth, requirements change impact, or defect density/distribution exceeds established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>.

Requirements Trends	

Indicator Interpretation	• Used to understand impact on system definition and impact on production.
	• Analyze this indicator for process performance and other relationships that may provide more "leading perspective".
	• Ops Concept quality may be a significant leading indicator of the requirements stability (may be able to use number of review comments; stakeholder coverage in defining the Ops Concept).
	• Care should be taken that the organization does not create incentives driving perceptions that all requirements change is undesirable. Note: Requirements changes may be necessary to accommodate new functionality.
	• Review of this indicator can help determine the adequacy of:
	    o Quantity and quality of Systems Engineers
	    o Infrastructure
	    o Process maturity (acquirer and supplier)
	    o Interface design capability
	    o Stakeholder collaboration across life cycle
	Funding by customer; financial challenge by the program management

Additional Information	
Related Processes	Stakeholder Requirements, Requirements Analysis, Architectural Design
Assumptions	Requirements Database, Change Control records, and defect records are maintained & current.
Additional Analysis Guidance	• May also be helpful to track trends based on severity/priority of changes • Defect leakage - identify the phases in which defect was inserted and found for each defect recorded.

Implementation Considerations	• Requirements that are not at least at the point of a draft baseline should not be counted.
	• Usage is driven by the correctness and stability of interfaces definition and design.
	    o Lower stability means higher risk of impact to other activities and other phases, thus requiring more frequent review.
	    o Applies throughout the life cycle, based on risk.
	    o Track this information per baseline version to track the maturity of the baseline as the system definition evolves.

User of Information	• Program Manager (PM) • Chief Systems Engineer (CSE) • Product Managers • Designers
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.2. System Definition Change Backlog Trends

System Definition Change Backlog Trends	
Information Need Description	
Information Need	Evaluate the backlog trends of the system definition to understand whether the changes are being made in a timely manner
Information Category	1. Schedule and Progress – Work Unit Progress 2. Also may relate to Process Performance - Process Efficiency 3. Also may relate to Product Stability
Measurable Concept and Leading Insight	
Measurable Concept	Are changes to the baseline being processed in a systematic and timely manner?
Leading Insight Provided	Indicates whether the change backlog is impeding system definition progress or system development quality/schedule. Also, an indication of potential rework due to changes not being available in a timely manner.
Base Measure Specification	
Base Measures	1. # of Request For Change (RFC) 2. Times of change: Start/interim/ approval/incorporated 3. # changes by priority (e.g., critical, high, medium, low; pri1, pri2, pri3, pri4) 4. # changes by cause (e.g., error, customer request, external, etc.) 5. # changes by approval disposition 6. Impact of each change (in estimated effort hours or range of hours)
Measurement Methods	1. Count the number of RFCs 2. Record from actual dates & times in the CM system 3. Count the number of changes per change priority 4. Count the number of changes per change cause 5. Count the number of changes per approval disposition 6. Based on engineering judgment and documented in the change request.
Unit of Measurement	1. RFC 2. Day, hour, minute 3. Changes (by priority) 4. Changes (by cause) 5. Changes (by disposition) 6. Effort hours
Entities and Attributes	
Relevant Entities	• Requests for Change (RFCs)
Attributes	• Requirement Changes • Time interval (e.g., monthly, quarterly, phase)
Derived Measure Specification	
Derived Measure	1. Approval/Closure rates 2. Cycle time statistical measures per attributes (e.g., mean, mode, min/max, dev.) 3. Priority density
Measurement Function	1. (# RFCs approved / # RFCs submitted) * 100 [per time interval] 2. Cycle time = Time approved – Time submitted (per attribute) 3. (# change by priority / # of changes)

Indicator Specification	
Indicator Description and Sample **See 3.2**	• Line graphs that show trends of RFC cycle time and backlog status over time. • Pareto graph or stacked bar graph that shows types, causes, and impact/severity of changes. • Line graphs that show projections of when the current backlog will be closed (using rate of arrivals, plus rate of closure) • Show thresholds of expected values based on experiential data.
Thresholds and Outliers	User defined.
Decision Criteria	Investigate and, potentially, take corrective action when the change backlog exceeds established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>.
Indicator Interpretation	Used to understand impact on system definition and development progress, and impact on time to market, and to identify associated risks. Also to provide insight to the level of capacity required to correctly process a change (resources, skill set).
Additional Information	
Related Processes	Stakeholder requirements, Requirements Analysis, Architectural Design, Requirements Management
Assumptions	Requirements Database and Change Control records are maintained & current.
Additional Analysis Guidance	• Also provides useful lagging information: Indicates that the SE processes are not being implemented effectively. • Are people reviewing the system definition at the appropriate level
Implementation Considerations	• Use whenever there are multiple changes in the approval queue, after baseline has been established. More frequent review needed when backlog increases, especially if changes have interdependencies. • Do not sample - collect all RFC data. • Analyze this indicator for other relationships that may provide more "leading perspective". • Relationship between open/unresolved changes needs to be considered.
User of Information	• Program Manager (PM) – associated risks affecting program execution, level of capacity required • Chief Systems Engineer (CSE) – impact of system definition and development activity, level of capacity required • Configuration Management Manager – process indicator
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.3. Interface Trends

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, and correctness of the definition of the system interfaces.
Information Category	1. Product size and stability – Functional Size and Stability 2. Also may relate to Product Quality and Process performance (relative to effectiveness and efficiency of validation)
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 Provided	• 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. • 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. • May indicate future need for different level or type of resources/skills.
Base Measure Specification	
Base Measures	1. # Interfaces 2. # Interface TBDs/TBRs (by selected categories; e.g., interval, milestone) 3. # Interface defects (by selected categories; e.g., type, cause, severity) 4. # Interface changes (by selected categories; e.g., type, cause) 5. Impact of each interface change (in estimated effort hours or range of hours) 6. Start/complete times of change
Measurement Methods	1. Count the number of interfaces identified and defined 2. Count the number of interface TBDs/TBRs among those interfaces identified and defined 3. Count the number of interfaces defects per category 4. Count the number of interface changes per category 5. Estimate the effort hours or range of effort hours expected for each change 6. Record from actual dates & times of interfaces complete in the CM system
Unit of Measurement	1. Interfaces 2. TBDs/TBRs 3. Defects 4. Changes 5. Effort hours 6. Date and time (Hours, minutes)

Entities and Attributes	
Relevant Entities	• Interfaces
Attributes	• Interface TBDs/TBRs • Interface Defects • Interface Changes • Time interval (monthly, quarterly, and phase)
Derived Measure Specification	
Derived Measure	1. % Interfaces approved 2. % Interfaces growth 3. TBDs/TBRs closure variance per plan 4. % Interfaces modified 5. Estimated Impact of Changes for time interval (in effort hours), 6. Defect profile 7. Defect density 8. Defect leakage (or escapes) 9. Cycle time for interface changes (each and average) 10. Rate of convergence of interfaces
Measurement Function	1. (# interfaces approved / # interfaces identified and defined)*100 as a function of time 2. ((# interfaces in current baseline - # interfaces in previous baseline) / (# interfaces in previous baseline) * 100 3. ((# TBDs/TBRs planned for closure – # TBDs/TBRs closed) / # TBDs/TBRs planned for closure) * 100 4. (# Interfaces modified / Total # interfaces) * 100 as a function of time 5. Sum of estimated impacts for changes (in effort hours) during defined time interval 6. Number of defects for each selected defect categorization 7. # of interface defects / # of interfaces as a function of time 8. Subset of defects found in a phase subsequent to its insertion 9. Elapsed time (difference between completion time and start times) or total effort hours for each change 10. Number of interfaces as a function of time
Indicator Specification	
Indicator Description and Sample **See 3.3**	Line or bar graphs that show trends of interface approval rates and TBD/TBR closure per plan. Stacked bar graph that shows types, causes, and impact/severity of changes. Show thresholds of expected values based on experiential data. Show key events along the time axis of the graphs. 1. Line or bar graphs that show growth of interfaces over time 2. Line or bar graphs that show % interfaces approved over time 3. Line or bar graphs that show % TBDs/TBRs not closed per plan 4. Line or bar graphs that show % interfaces modified, 5. Line or bar graphs that show estimated impact of changes for time interval (in effort hours) 6. Line or bar graphs that show defect profile (by types, causes, severity, etc.) 7. Line or bar graphs that show defect density 8. Stacked bar graph that shows types, causes, and impact/severity of changes on system design
Thresholds and Outliers	Organization dependent.

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> or a trend is observed per established guidelines <fill in organizational specific>.

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 (which may provide more leading "perspective").
	• Unfavorable trends indicate high risk during design, implementation and/or integration.
	• Care should be taken that the organization does not create incentives driving perceptions that all interface changes are undesirable.
	• Review of this indicator can help determine the adequacy of:
	    o Quantity and quality of Systems Engineers
	    o Infrastructure
	    o Process maturity (acquirer and supplier)
	    o Interface design capability
	    o Stakeholder collaboration across life cycle
	    o Funding by customer; financial challenge by the program management

Additional Information	
Related Processes	Stakeholder requirements, Requirements Analysis, Architectural Design
Assumptions	Requirements database, change control records, and defect records are maintained and current.
Additional Analysis Guidance	• May also be helpful to track trends based on severity/priority of changes • Defect leakage – identify the phases in which the defect was inserted and found for each defect recorded.

Implementation Considerations	• Usage is driven by the correctness and stability of interfaces definition and design.
	    o Lower stability means higher risk of impact to other activities and other phases, thus requiring more frequent review.
	    o Applies throughout the life cycle, based on risk.
	    o Track this information per baseline version to track the maturity of the baseline as the system definition evolves.

User of Information	• Program Manager (PM) • Chief Systems Engineer (CSE) • Interface Managers • Designers
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.4. Requirements Validation Trends

Requirements Validation Rate Trends	
Information Need Description	
Information Need	Understand whether requirements are being validated with the applicable stakeholders at each level of the system development.
Information Category	1. Product size and stability – Functional Size and Stability 2. Also may relate to Product Quality and Process performance (relative to effectiveness and efficiency of validation)
Measurable Concept and Leading Insight	
Measurable Concept	The rate and progress of requirements validation.
Leading Insight Provided	Provides early insight into level of understanding of customer/user needs: • Indicates risk to system definition due to inadequate understanding of the customer/user needs • Indicates risk of schedule/cost overruns, post delivery changes, or user dissatisfaction
Base Measure Specification	
Base Measures	1. # of requirements 2. # of requirements validated for time interval (planned) 3. # of requirements validated for time interval (actual) 4. Time (in hours or months) used for validation with the customer/end user
Measurement Methods	1. Count total # of requirements 2. Record # of requirements planned for validation for the time interval 3. Count # of requirements validated for the time interval 4. The start time and end time of the requirement validation process
Unit of Measurement	1-3. Requirement 4. Hours or person months
Entities and Attributes	
Relevant Entities	• Requirements
Attributes	• Time Interval (e.g., monthly, quarterly, phase, or event) • Stakeholder • Level of the architecture
Derived Measure Specification	
Derived Measure	1. Requirements validation rate (Rate at which requirements are validated with the customer/end user) 2. % requirements validated
Measurement Function	1. (# of requirements validated/unit time) 2. (# of requirements validated/total # requirements)*100
Indicator Specification	
Indicator Description and Sample **See 3.4**	1. Line graphs that show trends of validation rates per plan during a validation activity. 2. Table or graph showing time interval or events versus number or percent requirements validated (actual and planned).
Thresholds and Outliers	Organization dependent. Thresholds are phase dependent.

Requirements Validation Rate Trends	
Decision Criteria	Investigate and potentially take corrective action when the validation rate is lower than the established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>.
Indicator Interpretation	• Investigation is driven by deviation of actual rate, percentage or quantity from plan. • Lower validation rate compared to plan means higher risk, thus it would be reviewed more frequently. If actual validation (rate) is below planned validation (rate), there may be a need to increase staffing, increase review time with customer/end user, and/or review effectiveness of mission/requirements analysis processes pending causal analysis. This can in turn affect quality of system definition, validation, and customer satisfaction. An additional consideration is to examine whether requirements creep could be a source of the lower validation rate. • If the actual validation rate is exceeding the planned validation rate significantly, there may still be risk to consider. The planning process should be reviewed or the quality of the requirement validation method should be analyzed to ensure adequacy, if no process improvement was the reason for the deviation. If planning uses too low of validation rate, then efficiency may be lost. If validation process does not ensure adequate customer/user review, then there may be surprises during system validation.
Additional Information	
Related Processes	Stakeholder requirements, Requirements Analysis, Architectural Design.
Assumptions	Requirements database is maintained and validation rates can be obtained from project timeline. Assumes that appropriate historical database is available.
Additional Analysis Guidance	The timing for validation may be driven by large project reviews/events such as the PDR or CDR. These should be considered in the planning and analysis.
Implementation Considerations	• Usage is driven by the requirements validation rate. • Applies throughout the life cycle, based on risk, but in some cases it may be back-loaded (to SRR or later). • Could apply any time the project has requirements validation scheduled. • If the requirements validation rate is below plan, then there may further investigation warranted to determine what this issue/root cause is. • May also want to consider using "Requirements Validation Results Trends" that looks at causes of validation rejections, etc.
User of Information	• Chief Systems Engineer • V&V Lead • Program Manager • Customer or Third Party V&V
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.5. Requirements Verification Trends

Requirements Verification Trends	
Information Need Description	
Information Need	Understand whether requirements are being verified relative to plan at each level of the system development.
Information Category	1. Product size and stability – Functional Size and Stability 2. Also may relate to Product Quality and Process performance (relative to effectiveness and efficiency of verification)
Measurable Concept and Leading Insight	
Measurable Concept	The rate and progress of requirements verification.
Leading Insight Provided	Provides early insight into ability to meet customer/user requirements: • Indicates risk to system definition due to inadequate ability to meet the customer/user requirements • Indicates risk of schedule/cost overruns, post delivery changes, or customer/user dissatisfaction
Base Measure Specification	
Base Measures	1. # of requirements 2. # of requirements verified for time interval (planned) 3. # of requirements verified for time interval (actual) 4. Time (in months or hours) used for verification with customer/end user
Measurement Methods	1. Count total # of requirements 2. Record # of requirements planned for verification for the time interval 3. Count # of requirements verified for the time interval 4. The start time and end time of the requirement verification process
Unit of Measurement	1-3. Requirement 5. Hours or person months
Entities and Attributes	
Relevant Entities	• Requirements
Attributes	• Time Interval (e.g., monthly, quarterly, phase, or event) • Stakeholder • Level of the architecture
Derived Measure Specification	
Derived Measure	1. Requirements verification rate (Rate at which requirements are verified) 2. % requirements verified
Measurement Function	1. (# of requirements verified/unit time) 2. (# of requirements verified/total # requirements)*100
Indicator Specification	
Indicator Description and Sample **See 3.5**	1. Line graphs that show trends of verification rates per plan during a verification activity. 2. Table or graph showing time interval or events versus number or percent requirements verified (actual and planned).
Thresholds and Outliers	Organization dependent. Thresholds are phase dependent.

Requirements Verification Trends

Decision Criteria	Investigate and potentially take corrective action when the verification rate is lower than the established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>.
Indicator Interpretation	• Investigation is driven by deviation of actual rate, percentage or quantity from plan. • Lower verification rate compared to plan means higher risk, thus it would be reviewed more frequently. If the actual verification (rate) is below planned verification (rate), there may be a need to increase staffing, increase verification time with customer/end user, and/or review effectiveness of mission/requirements analysis processes pending causal analysis. This can in turn affect the quality of the system definition, system validation, and customer satisfaction. Lower verification could indicate a problem with test scheduling. • If the actual verification rate is exceeding the planned verification rate significantly, there may still be risk to consider. The planning process should be reviewed or the quality of the requirement verification method should be analyzed to ensure adequacy, if no process improvement was the reason for the deviation. If planning uses too low of verification rate, then efficiency may be lost.
Additional Information	
Related Processes	Stakeholder requirements, Requirements Analysis, Architectural Design.
Assumptions	Requirements database is maintained and verification rates can be obtained from project timeline. Assumes appropriate historical data is available.
Additional Analysis Guidance	The timing for verification may be driven by large project reviews/events such as the PDR or CDR. These should be considered in the planning and analysis.
Implementation Considerations	• Usage is driven by the requirements verification rate. Applies throughout the life cycle, based on risk. Could apply any time the project has requirements verification scheduled. • If the requirements verification rate is below plan, then there may be further investigation warranted to determine what this issue/root cause is. • May also want to consider using "Requirements Verification Results Trends" that looks at causes of verification failures, etc.
User of Information	• Chief Systems Engineer • Verification & Validation Lead • Program Manager • Customer or Third Party V&V
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.6. *Work Product Approval Trends*

Work Product Approval Trend	
Information Need Description	
Information Need	Evaluate work product progress to plan and the approval efficiency of the work products.
Information Category	1. Schedule & Progress – work unit progress 2. *Product Quality* 3. *Process Performance – process efficiency*
Measurable Concept and Leading Insight	
Measurable Concept	Are the system definition work products being approved as planned?
Leading Insight Provided	• Indicates that there may be a problem with identification of needs or transformation into requirements/design. • Indicates that the end product is not of high enough quality/maturity and may result in rework or need for changes in plan. • Indicates that the review process definition or implementation may be inadequate. • Indicates readiness for entry into review milestones • Early indication of where too much emphasis may be placed on quantity at the expense of quality (process breakdown or gaming the system)
Base Measure Specification	
Base Measures	1. Number of work products submitted, 2. Number of submitted work products for each approval disposition 3. Number of submitted work products by type
Measurement Methods	1. Count the number of work products total 2. Count the number of work products per approval disposition 3. Count the number of submitted work products by type
Unit of Measurement	1. Work Products 2. Work Products (rejected, approved, etc.)
Entities and Attributes	
Relevant Entities	• Work Products
Attributes	• Time interval (e.g., monthly, quarterly, phase) • Work Product Type • Work Product Approval Dispositions
Derived Measure Specification	
Derived Measure	1. Approval rate 2. Distribution of dispositions, 3. Approval rate performance
Measurement Function	1. (Number approved on first submittal) / (Number submitted) 2. Number of rejected work products before approval 3. (Actual approval rate) / (Planned approval rate)
Indicator Specification	
Indicator Description and Sample **See 3.6**	• Graphs that show trends of approval rates per plan during system definition. • Chart showing approval rate distribution by work product type.

Work Product Approval Trend	
Thresholds and Outliers	Organization dependent
Decision Criteria	Investigate and, potentially, take corrective action when the approval rate is lower than established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>. A positive trend can still indicate a risk or problem exists. E.g., a positive trend can be caused from reviews that are not effective or that there is too much effort being expended on work product preparation and review.
Indicator Interpretation	• Decreasing trends indicate greater risk in the review process or the understanding of user needs. • Increasing trends can indicate risk in thoroughness of reviews or that too much effort is being applied on work product preparation and review. • If external approval rate drops below threshold, it may indicate issue with effectiveness of Engineering Review Board, in-process reviews, and processes supporting product generation • Low external approval rates may also indicate that there is a problem with identification of needs or transformation into requirements/design. Examine together with the requirements and interface trends to see if there is a correlation in the results. • If internal approval rate drops below threshold, it may indicate issue with effectiveness of in-process reviews, and processes supporting product generation • In general, as approval rates drop (both internal and external), it could indicate too much emphasis is placed on quantity at the expense of quality (process breakdown or gaming the system). (If this is happening, this may also indicate that there is no objective standard for the work product.) • If internal approval rate gets close to 100%, it may indicate the internal reviews are not thorough enough. Review results together with the External Approval Rate. If external rate is lower, then the cause is probably the lack of thorough internal reviews. • If external approval rate gets close to 100%, may indicate that too much effort is being expended on KWP preparation and review. • Also can provide insight into adequacy of meeting planned/agreed-to milestones (internal and external). • Can provide insight into one influence of customer satisfaction.
Additional Information	
Related Processes	Review process
Assumptions	• Approval data for work product reviews is captured, retained, and current. • Approval rate based on 1st time submittals. • There is a consistent and validated set of criteria or objective standard for work product review and approval.
Additional Analysis Guidance	• A variation of this indicator is to look at the work product rejection rate. • Could also collect severity of cause of rejections (e.g., major, minor).

Work Product Approval Trend	
Implementation Considerations	• Do not sample - collect all work product approval data. • Use when there are numerous work products going through review and approval. Collect data and use the indicator for both internal (submitted to internal approval authority) and external (submitted to customer approval authority) work product reviews. Not intended for use during interim, incremental, in-process internal reviews. • Most effective if work product review and approval criteria or objective standards are defined, in order to ensure consistent application. • Time interval for data collection and reporting of analysis results may need to change through the life cycle based on phase and level of work product activity.
User Of The Data	• Chief Systems Engineer • Program Manager • Process Owners • Approval Authority
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.7. Review Action Closure Trends

Review Action Closure Trends	
Information Need Description	
Information Need	Evaluate design review action item progress to plan and closure efficiency.
Information Category	1. Schedule & Progress – milestone completion 2. Also may relate to Product Quality – efficiency; Process Performance – process efficiency; and Customer Satisfaction – customer feedback
Measurable Concept and Leading Insight	
Measurable Concept	Are early design review action items being closed according to plan?
Leading Insight Provided	• Design review actions items may be technical or management/ communication related. Large deviations for the planned closure may be indicative of larger, more complex tasks ahead or potentially is a sign of challenging personnel interfaces. In either case, this indicator reveals project risk in terms of rework and/or infeasible schedule. • May provide insight into readiness to move to the next step/stage/phase. • May be an indication of the feasibility of the plan with respect to cost, schedule, quality, performance, or functionality.
Base Measure Specification	
Base Measures	1. # Action Items for the time interval 2. # Action Items per disposition (opened, closed, overdue, etc.) at end of time interval 3. # Action Items per priority (e.g., critical, major, minor) at end of time interval 4. # of Action Items per Design Review event 5. Impact for each action item (e.g., high, medium, low or effort hours)
Measurement Methods	1. Count the total number of action items 2. Count the number of action items for each disposition at the end of the time interval 3. Count the number of action items for each priority at the end of the time interval 4. Count the number of action items assigned for each design review event 5. Estimate the impact of each action item using engineering judgment
Unit of Measurement	1. Action items 2. Action items 3. Action items 4. Action items 5. Assessed qualitative impact or effort hours
Entities and Attributes	
Relevant Entities	• Action items
Attributes	• Action Disposition (Open, Closed, Overdue, etc.) • Priority (e.g., Critical, Major, Minor) • Impact (e.g., High, Medium, Low) • Time interval (e.g., monthly, quarterly, phase),

Derived Measure Specification	
Derived Measure	1. Closure rates 2. Action item closure performance 3. Variance from thresholds (for number of action items assigned at design review or closure performance)
Measurement Function	1. Number of action items closed over time 2. (Action items closed over time interval) / (Action items planned for closure over time interval) 3. Difference between observed values and threshold values
Indicator Specification	
Indicator Description and Sample **See 3.7**	• Graph(s) showing trends of closure rates and action item performance. • May include bar graph showing total number of actions per review. • Graphs may show results by priority of actions. • Show thresholds of expected values based on experiential data. • Show key events along the time axis of the graph(s).
Thresholds and Outliers	Organization dependent
Decision Criteria	Investigate and, potentially, take corrective action when the closure rate or Overdue action items exceed established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>.
Indicator Interpretation	• Large deviations for the planned closure may be indicative of larger, more complex tasks ahead or potentially is a sign of challenging personnel interfaces. • A backlog in the action item closure indicates project risk in terms of rework and/or infeasible schedule, especially if the backlog has higher priority or impact actions. • If the backlog of action items are related to the technical solution definition, then it indicates there is additional technical risk that should be assessed before proceeding to the next phase, especially if the backlog has higher priority or impact actions. Large number of lingering action items may indicate requirements instability, immature architecture/design, or inadequate stakeholder buy-in. This may be caused by inadequate pre-acquisition systems engineering, including ICD, AoA, AMA (number of review comments; adequate coverage of alternatives in the solution space, etc.) • The backlog of action items may also be an indication of inadequate quantity or quality (experience or skill mix) of personnel, inadequate program support infrastructure, process maturity/compliance problems, or inadequate program funding. • Significantly larger number of technical actions assigned at a design review than expected (based on historical data or thresholds) may indicate unacceptable technical risks and may impact readiness.
Additional Information	
Related Processes	Review process
Assumptions	• Review minutes/records are maintained & current. • Assumes standard definitions for reviews and life cycle for a program or business.

Additional Analysis Guidance	• Usage is driven by the status of Design Review action item closure. Lower closure than planned, or greater the number of open action items, means higher risk, thus it would be reviewed more frequently. Applies to the Design phase. • Analyze results by the priority of the actions to determine performance on high priority actions that may have the greatest impact. • Analyze the closure rate in conjunction with quality of the action responses (i.e., closure does not equate to quality).
Implementation Considerations	• Includes action items from peer reviews, inspections, technical exchange meetings, in addition to those from large formal reviews/events • Do not sample - collect all Design review action item data. • Should include stakeholder collaboration across life cycle • Ensure common definition of reviews and life cycle • Should use clear, consistent closure criteria for actions
User Of The Data	• Chief Systems Engineer • Product Manager
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.8. Technology Maturity Trends

Technology Maturity Trends	
Information Need Description	
Information Need	Determination of the readiness of new technologies and the obsolescence of currently used technologies in order to maintain a useful and supportable technology base.
Information Category	Technology Effectiveness
Measurable Concept and Leading Insight	
Measurable Concept	The potential impact (beneficial or adverse) of technology changes on the future of the program.
Leading Insight Provided	• Indicates that technology opportunities exist that need to be examined and may warrant product changes. A business case needs to be developed to estimate schedules, costs, and benefits (e.g., profit, market share, product performance) of introducing new technology. • Indicates technology is becoming obsolete and may be a candidate for replacement. A business case needs to be developed to estimate schedules (e.g., likely obsolescence dates, time to introduce replacements), costs (e.g., sustaining, development), and benefits (e.g., reduced support costs, improved product performance or customer satisfaction). • Trend of obsolescence exposure gives an indication of when to take action due to obsolescence risk. • Lagging technical maturity progress may provide insight into additional risk of meeting KPPs. • Should help avoid surprises from obsolescence and plan for right timing of technology insertion of new technologies.
Base Measure Specification	
Base Measures	1. Number of technology obsolescence candidates identified 2. Number of critical/beneficial technology opportunities identified 3. Technology readiness level (for each new technology opportunity) 4. Number of technology obsolescence candidates realized 5. Number of technology opportunity candidates realized 6. Expected time to realization (of technology readiness or obsolescence) 7. Actual time to realization (of technology readiness or obsolescence) 8. Expected cost for realization (of technology readiness or obsolescence) 9. Actual cost for realization (of technology readiness or obsolescence) 10. Probability of technology insertion/phase-out 11. Probable impact of technology insertion/phase-out 12. Actual impact of technology insertion/phase-out

<table>
<tr><th colspan="2">Technology Maturity Trends</th></tr>
<tr><td>Measurement Methods</td><td>1-3. Empirical analysis and expert opinion based on the following sources:
a. Industry contacts and associations
b. Technology forecast reports
c. Technical staff
4. Track technology obsolescence candidates until realized
5. Track technology opportunity candidates until realized
6. Empirical analysis and expert opinion based on sources listed above
7. Record actual time to realization (of technology readiness or obsolescence)
8. Empirical analysis and expert opinion based on sources listed above
9. Record actual cost for realization (of technology readiness or obsolescence)
10. Empirical analysis and expert opinion based on sources listed above
11. Empirical analysis and expert opinion based on sources listed above
12. Empirical analysis and expert opinion based on sources listed above</td></tr>
<tr><td>Unit of Measurement</td><td>1. Technology obsolescence candidates
2. Technology opportunity candidates
3. Technology readiness level
4. Technology obsolescence candidates
5. Technology opportunity candidates
6. Time
7. Time
8. Cost
9. Cost
10. Probability
11. Cost and schedule
12. Cost and schedule</td></tr>
<tr><th colspan="2">Entities and Attributes</th></tr>
<tr><td>Relevant Entities</td><td>• Technology candidates</td></tr>
<tr><td>Attributes</td><td>• New Technology opportunities
• Existing technology obsolescence</td></tr>
<tr><th colspan="2">Derived Measure Specification</th></tr>
<tr><td>Derived Measure</td><td>1. Technology opportunity exposure
2. Technology obsolescence exposure</td></tr>
<tr><td>Measurement Function</td><td>1. Technology opportunity exposure: probability * impact (for each opportunity)
2. Technology obsolescence exposure: probability * impact (for each obsolescence candidate)</td></tr>
<tr><th colspan="2">Indicator Specification</th></tr>
<tr><td>Indicator Description and Sample

See 3.8</td><td>• A graph showing trend of technology opportunity exposure, obsolescence exposure and impact of change.
• Graph or table showing variances between estimated and actual.
• Graph showing trend of technology readiness levels over time.</td></tr>
<tr><td>Thresholds and Outliers</td><td>Organization dependent</td></tr>
<tr><td>Decision Criteria</td><td>Investigate and, potentially, take action when total technology opportunity exposure, technology obsolescence exposure, and/or impact of change exceeds organizational criteria.</td></tr>
</table>

Technology Maturity Trends	
Indicator Interpretation	• Provide early warning of potential obsolescence issues • Provide early assessment of impact of changes • Identify when conditions are right to take advantage of new technology opportunities
Additional Information	
Related Processes	Planning, Decision Making, Architectural Design, and Production
Assumptions	Technology opportunities and obsolescence candidates are captured. Technical staff assesses probability, impact, and timeframe of insertion or replacement.
Additional Analysis Guidance	• Collect data for each identified technology opportunity or obsolescence candidate. • Need to consider analysis based on intended life of the system/product.
Implementation Considerations	Use when 1) there is a risk of technology obsolescence that may impact the system; or 2) critical/beneficial technologies are in development. Care should be taken to ensure that "technology push" of introducing "new" technology provides improved value or capability to the customer/consumer/user (unless the business decision and marketing approach is deliberately one of "new technology"). Obsolescence issues may prevent the organization from making/maintaining the product. Need to ask: 1) What can be done with the new technology? – Is the market ready? 2) How can it be incorporated into the architecture and design? 3) What risks are introduced as a result of new technology and product obsolescence? "Best/worst/most likely" cases should be analyzed to understand the spectrum of possible outcomes, their individual likelihood, and the effects on decisions. Reliance on either extreme for technology maturity or obsolescence can lead to suboptimal decisions.
User of Information	• Program/project Manager • Chief Systems Engineer • Chief Architect • Customer • R&D groups
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.9. *Risk Exposure Trends*

Risk Exposure Trends	
Information Need Description	
Information Need	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.
Information Category	1. Product quality 2. Schedule and progress 3. Cost and resource
Measurable Concept and Leading Insight	
Measurable Concept	Assessment of program effectiveness in managing/mitigating risks • Is the risk exposure going to impact the system solution? • Is the SE effort managing the exposure successfully?
Leading Insight Provided	Indicates whether the program is effectively managing the program risks as shown by predicted exposure ratings over time. • Assessment of risk exposure impacts to the system solution • Assessment of the SE effort in successfully managing the exposure
Base Measure Specification	
Base Measures	At each time interval: 1. Number of risks 2. Probability of occurrence 3. Impact of occurrence 4. Criticality (Urgency to address – if used in risk management process) 5. Planned handing actions (per risk) 6. Actual handing actions (per risk) 7. Risk dispositions (new, open, closed, etc.)
Measurement Methods	1. Count of risks in database 2. Engineering judgment influenced by historical data (if any) or risk models 3. Engineering judgment influenced by historical data (if any) or risk models 4. Engineering judgment influenced by historical data (if any) or risk models 5. Count from risk repository 6. Count from risk repository 7. Count of risks for each disposition
Unit of Measurement	1. Number (of risks, tasks, events) 2. Probability value 3. Performance value/dollar/schedule differential(s) 4. Rating corresponding to time interval 5. Number (of tasks, events) 6. Number (of tasks, events) 7. Number (of risks for each disposition)
Entities and Attributes	
Relevant Entities	• Risk candidates
Attributes	• Time interval (e.g., monthly, quarterly, phase)

Derived Measure Specification	
Derived Measure	Factored Risk Exposure *[could be in terms of $, time, or technical parameters]*
Measurement Function	1. Probability * Impact *[behavior over time]* 2. Probability * Impact * Criticality *[behavior over time - variant if criticality (or urgency) is used]*
Indicator Specification	
Indicator Description and Sample **See 3.9**	1. Risk magnitude/reduction line graph over time that shows trends for each risk category/rating. 2. Table of planned vs. actual risk exposure. • Planned vs. actual over time • Information displayed graphically • See sample charts
Thresholds and Outliers	Organization and/or program dependent.
Decision Criteria	Investigate and, potentially, take corrective action when the exposure trends predict that the risk exposure thresholds are being approached or may become out of control.
Indicator Interpretation	Impact on program execution in meeting Cost, Schedule, Performance, Quality. If the risk exposure continues to grow or not be reduced, the customer satisfaction will be negatively impacted due to resulting cost, schedule, or technical impacts.
Additional Information	
Related Processes	Risk Management, Program Management
Assumptions	• Information is readily available, current, and maintained in a Risk Management repository. • An active risk management program, which is continuously executed throughout the life of a program, exists.
Additional Analysis Guidance	May use all data or just concentrate on the highest priority risks.
Implementation Considerations	• Align with scheduled reviews (e.g., Risk, IPT, SE, and program) • Aids in identifying trouble spots in terms of performance, cost, and schedule, especially with the collection of categories and sources to share across enterprises to foster lessons learned. Note: For this indicator, the concept of risk does not include opportunities.
User of Information	• Program Manager • Chief Engineer • Risk Manager
Data Collection Procedures	• See Appendix A
Data Analysis Procedures	• See Appendix A

4.10. Risk Handling Trends

Risk Handling Action Trends	
Information Need Description	
Information Need	Evaluation of risk management program to assess whether the plan/action items have been properly executed.
Information Category	1. Product quality 2. Schedule and progress
Measurable Concept and Leading Insight	
Measurable Concept	Assess how successful the SE effort is in mitigating the risks • Are the risk handling/treatment actions being executed and closed as planned? • Is the SE effort driving the closure of the risks?
Leading Insight Provided	Indicates whether the program is proactively handling/treating potential problems or risks at the appropriate times in order to minimize or eliminate their occurrence and impacts to the program. If the actions are not closing per plan, then there is a higher probability that risks will be realized. This insight can identify where additional action may be needed to avoid preventable problems or reduce impacts. This indicator may also identify that the program does not have an iterative or continuous process implementation for risk management. Thus, new risks may not be identified and handled, and may affect the program and technical effectiveness/success.
Base Measure Specification	
Base Measures	1. Number of risk handling actions 2. Risk handling action disposition (new, open, overdue, closed on time, closed after overdue, etc.) 3. Risk level of associated risks (red, yellow, green - for filtering purposes to isolate progress on actions for high priority risks) 4. Date of handling action
Measurement Methods	1. Count of risk handling actions from risk management repository 2. Count of risk handling actions for each disposition 3. Count of risks for each risk level 4. Record actual date of risk handling action initiation
Unit of Measurement	1-3. Number (of action items) 4. Date
Entities and Attributes	
Relevant Entities	• Risk handling actions
Attributes	• Time interval
Derived Measure Specification	
Derived Measure	1. % risk handling actions closed on time *[per risk level]* 2. % risk handling actions overdue *[per risk level]* 3. % risks that met risk reduction plan
Measurement Function	1. ((# actions closed in time interval)/(# actions planned to close in time interval)) * 100 *[per risk level]* 2. ((# actions overdue in time interval)/(# actions planned to close in time interval)) * 100 *[per risk level]* 3. ((# of risks reduced in time interval)/(# of risks planned to be reduced in time interval)) * 100

Indicator Specification	
Indicator Description and Sample See 3.10	1. Opened Closed Actions: A line chart plots the number of Actions that are open and closed including Overdue Actions. 2. Age of Actions: A stacked column chart shows the distribution of open actions according to the age of the risk handling action. 3. Actions Priority: A stacked column chart displays the number of open actions that are associated with each of the priority levels. Risk level of associated risks (High, Medium and Low - for filtering purposes to isolate progress on actions for high priority risks. 4. Actions Dispositions: A stacked column chart depicts the number of open Actions that are associated with each of the dispositions (For example, Assigned, Analyzed, Approved, Implemented, Verified and Closed).
Thresholds and Outliers	Organization and/or program dependent.
Decision Criteria	Investigate and, potentially, take corrective action when risk reduction and risk handling action closure are below threshold or expectations. Objective for both is generally near 100%.
Indicator Interpretation	Used to identify whether or not effort is being adequately applied to risk handling/treatment activities. Impact on staffing, planning, development progress, and product delivery. If the actions are not closing per plan, then there is a higher probability that risks will be realized. This insight can identify where additional action may be needed to avoid preventable problems or reduce impacts.

Additional Information	
Related Processes	Risk Management, Program Management
Assumptions	• Information is readily available, current, and maintained in a Risk Management repository. • An active risk management program, which is continuously executed throughout the life of a program, exists.
Additional Analysis Guidance	• May use all data or just concentrate on the highest priority risks. • Effective closure of risk handling actions should positively affect risk exposure.
Implementation Considerations	• Applies to all tasks (i.e., PM, SE, SW, …) throughout program life cycle. • Align with scheduled reviews (e.g., Risk, IPT, SE, and program). • The Risk and Opportunity Management process is owned by Program Management and is facilitated for execution by Systems Engineering. Not only are these indicators for Systems Engineering, but they are most likely indicators of overall program performance and health.
User of Information	• Program Manager • Chief Engineer • Risk Manager
Data Collection Procedure	• See Appendix A
Data Analysis Procedure	• See Appendix A

4.11. Systems Engineering Staffing and Skills Trends

Systems Engineering Staffing & Skills Trends	
Information Need Description	
Information Need	Evaluate the adequacy of the SE effort, skills, and experience provided on the program to meet program objectives.
Information Category	Resources and Cost – Personnel Effort
Measurable Concept and Leading Insight	
Measurable Concept	Is SE effort being applied to the project activities consistent with proven organizational or industry practice? Do the staff members have the appropriate skills and experience to achieve assigned tasks?
Leading Insight Provided	• Indicates whether the expected level of SE effort, staffing, and skill mix is being applied throughout the life cycle based on historical norms for successful projects and plans. • Indicates gap or shortfall of effort, skills, or experience that may lead to inadequate or late SE outcomes. • Planned staffing can be compared to projected availability through the life cycle to provide an earlier indication of potential risks.
Base Measure Specification	
Base Measures	1. Total effort in hours by task, activity, or event (Planned) 2. Total effort in hours by task, activity, or event (Actual) 3. SE effort in hours by task, activity, or event (Planned) 4. SE effort in hours by task, activity, or event (Actual) 5. SE effort in hours by skill and experience (Planned) 6. SE effort in hours by skill and experience (Actual) 7. # of SE Staff by task, activity, or event (Planned) 8. # of SE Staff by task, activity, or event (Actual)
Measurement Methods	1. Record effort hours from plan by task, activity, or event (may also include experience) 2. Count effort hours by task, activity, or event 3. Record effort hours from plan by task, activity, or event 4. Count effort hours by task, activity, or event 5. Record effort hours from plan by skill and experience (Novice, Junior, Senior, etc.) 6. Count effort hours by skill and experience (Novice, Junior, Senior, etc.) 7. Record the number of SE staff planned for the task, activity, or event 8. Count the number of SE staff actually applied to the task, activity, or event
Unit of Measurement	1-6. Hours 7-8. Full-time equivalent staff
Entities and Attributes	
Relevant Entities	• Effort Hours • Skills • Headcount
Attributes	• Time interval (e.g., monthly, quarterly, phase), • Task or activity • Experience level (Novice, Junior, Senior, etc.)

Derived Measure Specification	
Derived Measure	The following may be useful for both the total project and for the specific activities, tasks, or events. 1. % of SE Effort (SE effort / total effort) – Planned 2. % of SE Effort (SE effort / total effort) - Actual 3. % of SE Staffing per plan (SE staffing / total staffing) - Planned 4. % of SE Staffing per plan (SE staffing / total staffing) – Actual 5. Variance of SE Effort (per task and total) 6. Variance of SE Staffing (per task and total) 7. Variance of quantity of SE skills (per given SE skill)
Measurement Function	1. Planned SE Effort / Planned Total Effort 2. Actual SE Effort / Actual Total Effort 3. Planned SE Headcount / Planned Total Headcount 4. Actual SE Headcount / Actual Total Headcount 5. (Planned SE effort hours) – (Actual SE effort hours) 6. (Planned SE headcount) – (Actual SE headcount) 7. (Planned hours of a given SE skill) – (Actual hours of a given SE skill) [consider experience also, as applicable]
Indicator Specification	
Indicator Description and Sample **See 3.11**	1. Line graphs that show trends of actual SE effort and SE staffing versus plan across the life cycle. Show key events along the time axis of the graphs. 2. Bar charts or stacked bar charts showing the distribution of actual SE effort per task, activity, event or other relevant breakdown against the experiential data for successful projects or against plan. 3. Bar charts showing distribution of actual and planned SE staffing hours by skill. Can use a stacked bar graph to show experience distribution within a skill. 4. Line graphs showing the trends of the most critical SE skills against plan. Show a plan line and actual line over time for each critical skill.
Thresholds and Outliers	Organization dependent
Decision Criteria	Based on the trend, investigate and, potentially take corrective action when the SE effort/skills for a task, event, or portion of the life cycle exceeds established thresholds (positive or negative) or a trend is observed per established guidelines.
Indicator Interpretation	• Lack of meeting planned SE effort or staffing with required skills/experience (i.e., below plan thresholds) potential missed milestones, schedule slips, and/or reduced quality. • Staff hours or headcount that is higher than plan indicates potential cost overrun. • Effort hours, skills and experience should be reviewed together against plan for tasks or activities. This indicates whether the right amount of effort is being applied with the right skills and experience. • Planned staffing can be compared to projected availability through the life cycle to provide an earlier indication of potential risks. • Provides insight into impact of the quantity of systems engineering effort (both hours and headcount) on the overall performance of the project. • Meeting planned effort hours with too few staff will likely result in longer term overtime issues, including impact on cost and quality.

Additional Information	
Related Processes	Planning, Control
Assumptions	• Time records that capture SE effort are maintained and current. • SE skill capabilities and experience of personnel are known and maintained. • The Staffing Plan identifies not only roles and quantity, but includes identification of critical skills and when they are needed.
Additional Analysis Guidance	• Can use to aid in trade-off of SE effort versus level/skills. • Should analyze the effort and skills trends together to ensure the right skill mix for the effort.
Implementation Considerations	1. Do not sample - collect all SE effort data and establish applicable distribution. 2. The SE effort is dependent on the tasks/activities the project is responsible for. The project would define the tasks/activities included and would determine whether to track at a total aggregate level or at a lower level. 3. This is most effective, if the distribution of SE skills is identified, an evaluation of personnel against the SE skill set is maintained, and the tracking is performed to ensure the personnel with the right skills are being provided. 4. Consider the utility and importance of staffing measures that span companies through teaming agreements.
User Of The Data	• Program Manager • Chief Systems Engineer • Other Managers
Data Collection Procedures	• See Appendix A
Data Analysis Procedures	• See Appendix A

4.12. Process Compliance Trends

Process Compliance Trends	
Information Need Description	
Information Need	Evaluate project defined SE process performance for compliance and effectiveness.
Information Category	Process Performance – process compliance and effectiveness
Measurable Concept and Leading Insight	
Measurable Concept	To what extent are the SE processes in place and being used on the program?
Leading Insight Provided	• Indicates where process performance may impact other processes, disciplines, or outcomes of the project. • General non-compliance indicates increased risk in ongoing process performance and potential increases in variance. • Non-compliance of individual processes indicates a risk to downstream processes.
Base Measure Specification	
Base Measures	1. Tasks satisfied or activities completed 2. Tasks or activities with discrepancies or tailoring 3. Number of discrepancies by discrepancy severity qualifier (minor, major) 4. Number of discrepancies by discrepancy category
Measurement Methods	4. Count the number of tasks satisfied 5. Count the number of tasks with discrepancies 6. Count the number of discrepancies by severity 7. Count the number of discrepancies by category or process activity
Unit of Measurement	1. Tasks or process activities 2. Tasks or process activities 3. Discrepancies 4. Discrepancies
Entities and Attributes	
Relevant Entities	• Tasks
Attributes	• Time interval (e.g., monthly, quarterly, phase) • Discrepancy severity • Discrepancy category
Derived Measure Specification	
Derived Measure	1. % Processes with discrepancies 2. Profile of discrepancies 3. High risk processes
Measurement Function	1. Number of processes with discrepancies divided by number of processes (audited) 2. Number of minor, major discrepancies over time 3. Number of processes with major findings or with numerous minor findings

Indicator Specification	
Indicator Description and Sample **See 3.12**	1. Pareto chart showing quantity of discrepancies for processes from highest to lowest (allows visual identification of those requiring investigation). Show thresholds of expected values based on experiential data. 2. Graph illustrating the number discrepancies or audit findings per process or depicting the amount (percentage or number) of tailoring per process. The data can also be presented to highlight audits findings or process changes categorized according to type, or priority. Furthermore, a business or program might set thresholds for the acceptable amount of findings or tailoring.
Thresholds and Outliers	Organization dependent
Decision Criteria	Investigate and, potentially, take corrective action when the % of processes with discrepancies or number of discrepancies exceeds established thresholds <fill in organization specific threshold> or a trend is observed per established guidelines <fill in organizational specific>. Particularly pay attention to critical processes.
Indicator Interpretation	• General non-compliance indicates increased risk in ongoing process performance and potential increases in variance. • Non-compliance of individual processes indicates a risk to downstream processes.
Additional Information	
Related Processes	All processes
Assumptions	Process audits are conducted and records are maintained & current. Base measures data are available from process audits.
Additional Analysis Guidance	• Usage is driven by the process audit plan • Review together with the work product approval indicators • Although lagging, this indicator also identifies where additional training or quality surveillance may be needed.
Implementation Considerations	• All processes do not need to be audited during all audit periods. Audit those that are most important to success or performed most often during that period. • Need to identify the processes that are downstream from the process observed to provide a leading view. • The lack of a process audit plan is an indicator of risk in this area. • Best to have a non-advocate/independent party involved • Frequency of review is dependent on schedule duration, scope, and composition of the program. • Discrepancy categories are organization dependent • Discrepancy high risk thresholds are organization dependent
User Of The Data	• Chief Systems Engineer • Process Lead • Quality Assurance Manager
Data Collection Procedures	• See Appendix A
Data Analysis Procedures	• See Appendix A

4.13. Technical Measurement Trends

Technical Measurement Trends	
Information Need Description	
Information Need	Understand the risk, progress, and projections regarding a system element or system of interest achieving the critical technical performance requirements.
Information Category	Technology Effectiveness • Technology Suitability and Volatility Product Quality • All categories
Measurable Concept and Leading Insight	
Measurable Concept	To what extent are the performance parameters feasible and being achieved per plan?
Leading Insight Provided	Indicates whether the product performance is likely to meet the needs of the user based on trends. • Project the probable performance of a selected technical parameter over a period of time • Project the probable achievement of system balance (satisfaction of all TPMs). Indicates feasibility of alternatives and impact of potential technical decisions. • Assessments of the program impact for proposed change alternatives 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 Measure Specification	
Base Measures	Specific base measures are dependent on the MOE/MOP/TPM; general base measures are: 1. Planned Values of Technical Measure (at each time interval or milestone) 2. Actual Values of Technical Measure (at each time interval or milestone) 3. Priority (e.g., critical, major, minor or High, medium, low)
Measurement Methods	1. Record planned values of the MOE/MOP/TPM 2. Record actual values of the MOE/MOP/TPM 3. Count the number of requirements for each priority
Unit of Measurement	Depends on MOE/MOP/TPM - measured values (e.g., miles, pounds, watts, MTBF, etc.)
Entities and Attributes	
Relevant Entities	• Technical Requirements
Attributes	• Time interval (e.g., monthly, quarterly, phase), • Other attributes are dependent on the MOEs/MOPs/TPMs chosen.

Technical Measurement Trends	
	Derived Measure Specification
Derived Measure	1. Delta performance (planned vs actual) 2. Delta performance to meeting thresholds and objectives 3. % Sum|normalized deviations from plan| across all measures
Measurement Function	1. Delta performance$_{plan}$ = Planned performance – Actual performance 2. Delta performance$_{threshold}$ = Threshold performance – Actual performance 3. Sum |Delta performance$_{plan}$/Planned Performance|
	Indicator Specification
Indicator Description and Sample **See 3.13**	Trends graphs/charts of MOEs (or KPPs), MOPs, TPMs, and margins. Graphical representation will be dependent on the specific MOE/MOP/TPM chosen.
Thresholds and Outliers	Organization and/or contract dependent.
Decision Criteria	Investigate and, potentially, take corrective action when the values of the MOEs/MOPs/TPMs exceed the tolerance bands (e.g., acceptable risk range) <fill in MOE/MOP/TPM specific tolerance band values> or a trend is observed per established guidelines <fill in specific details>.
Indicator Interpretation	• Technical progress behind plan indicates that risk is increasing. Technical progress that violates the defined “tolerance band” creates an issue to be managed with corrective action. • Technical progress ahead of plan indicates risk is decreasing. Technical progress that satisfies the objective effectively closes the risk.
	Additional Information
Related Processes	Technical Risk, Requirements Analysis, Modeling, Design and Integration
Assumptions	MOE/MOP/TPM measurement records are maintained & current. This includes accurate and current measured values from analysis, prototype, and test.
Additional Analysis Guidance	See Technical Measurement Guide (PSM, INCOSE)
Implementation Considerations	• TPMs should be derived from KPPs or other critical requirements that affect the technical success of the program. • 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. • Solid Systems Engineering Foundation - Staff, Requirements Analysis, Architecture, Implementation, Integration, Verification, Facilities.

Technical Measurement Trends	
User Of The Data	• Chief Systems • Chief Systems Engineer • Product Manager • Quality Assurance Manager
Data Collection Procedures	• See Appendix A
Data Analysis Procedures	• See Appendix A

5. REFERENCES

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APPENDIX A

The following information is very organization or project dependent and will not be defined in this guidance. It is provided in this one indicator (Requirements Growth) as an example only. The organization or project measurement plans should include this information following the guidance of PSM.

Data Collection Procedure (for each Base Measure) *Complete this section for each base measure listed in each measurement information specification*	
Frequency of Data Collection	Collect at least monthly; more frequently during peak activity periods. Do not sample - collect all requirements data.
Responsible Individual	Measurement Analyst, Requirements Manager, Configuration Management Manager
Activity in which Collected	From concept and system definition through system deployment
Potential Sources of Data	Requirements Database, Change Board records, defect data
Typical Tools Used in Data Collection	Requirement Database, Configuration Management Database
Verification and Validation	Check data against Configuration Management records.
Repository for Collected Data	User defined.
Data Analysis Procedure (for each Indicator)	
Frequency of Data Reporting	Biweekly to monthly, depending on the level of activity
Responsible Individual	Measurement Analyst
Activity in which Analyzed	From concept and system definition through system deployment
Source of Data for Analysis	Requirements Database, Change Board records, defect data
Tools Used in Analysis	Spreadsheet, statistical analysis, measurement analysis
Review, Report, or User	Chief SE, Product Manager.

APPENDIX B - Acronyms

AoA	Analysis of Alternatives
AMA	Analysis of Material Approaches
CDR	Critical Design Review
DoD	United States Department of Defense
ICD	Initial Capabilities Document
INCOSE	International Council on Systems Engineering
KPP	Key Performance Parameter
LAI	Lean Aerospace Initiative
LMCO	Lockheed Martin
MIT	Massachusetts Institute of Technology
MOE	Measure of Effectiveness
MOP	Measure of Performance
PDR	Preliminary Design Review
PSM	Practical Software & Systems Measurement
RFC	Request for Change
SE	Systems Engineering
SEARI	Systems Engineering Advanced Research Initiative
SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Plan
SoS	System of Systems
SRR	System Requirements Review
SSCI	Systems and Software Consortium, Incorporated
TBD	To Be Determine
TBR	To Be Resolved
TPI	Technical Performance Index
TPM	Technical Performance Measure(ment)
V&V	Verification & Validation
WG	Working Group