NASA Common Leading Indicators
Detailed Reference Guide

National Aeronautics and Space Administration
Office of the Chief Engineer
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1.0 Background

1.1. Why Is NASA Defining a Set of Common Leading Indicators?

In the FY 2011 House Appropriations Report, Congress directed NASA to develop a set of measurable criteria to assess project design stability and maturity at crucial points in the development life cycle. These criteria or metrics would allow NASA to objectively assess design stability and minimize costly changes late in development. The report further directed the NASA Chief Engineer to (1) develop a common set of measurable and proven criteria to assess design stability and (2) amend NASA's systems engineering policy to incorporate the criteria. As such, the Office of the Chief Engineer undertook an effort to determine a set of common metrics—leading indicators—to assess project design stability and maturity at key points in the life cycle.

NASA's response was three-fold. First, NASA identified three critical parameters that all programs and projects are required to report periodically and at life-cycle reviews. These are mass margin, power margin, and Requests for Action (RFAs) (or other means used by the program/project to track review comments). These three parameters were placed into policy via NPR 7123.1, *NASA Systems Engineering Processes and Requirements*. Second, NASA identified and piloted a set of augmented entrance and success criteria for all life-cycle reviews as documented in Appendix G of NPR 7123.1. Third, NASA identified a common set of programmatic and technical indicators to support trending analysis throughout the life cycle. These highly recommended leading indicators have been codified in the Program/Project Plan and Formulation Agreement Templates of NPR 7120.5, *NASA Space Flight Program and Project Management Requirements*.

Since the 2011 report, NASA has continued to identify indicators that would help predict future issues not only during the design phase, but also throughout the life cycle. This Leading Indicator Guide provides detailed information on each of the required and highly recommended indicators as well as a list of potential other indicators and measures that each program or project might consider (See Appendix D).

Each program and project selects a set of technical and programmatic indicators that best fits their type, size, complexity, and risk posture. The selected set of indicators is included in the Program or Project Plan per the templates given in NPR 7120.5. These indicators are then measured and tracked over time and reported at each of their life cycle (see NPR 7123.1 Appendix G tables) and Key Decision Point reviews. Similar indicators also may be tracked by an independent review team or Standing Review Board (SRB) who may report out at these reviews to provide a check and balance viewpoint. The set of indicators the independent review team or SRB will be tracking are typically identified in the Terms of Reference that documents the nature, scope, schedule, and ground rules for the independent assessment of the program/project.

1.2. Required and Recommended Set of Common Leading Indicators

A summary of the set of required and recommended common leading indicators that each program/project should consider includes:

- Requirement Trends (percent growth, To Be Determined (TBD)/To Be Resolved (TBR) closures, number of requirement changes)
- Interface Trends (% Interface Control Document (ICD) approved, TBD/TBR burndown, number of interface change requests)
- Verification Trends (closure burndown, number of deviations/waivers approved/open)
- Review Trends (RID/RFA/Action Item burndown per review)
- Software-unique Trends (number of requirements/features per build/release vs. plan)
- Problem Report/Discrepancy Report Trends (number open, number closed)
- Technical Performance Measure (mass margin, power margin)
- Program/project-specific Technical Indicators
- Manufacturing Trends (number of nonconformance/corrective actions)
- Cost Trends (plan vs. actual, Unallocated Future Expenditures (UFE) usage, Earned Value Management (EVM))
- Schedule Trends (critical path slack/float, critical milestone dates)
- Staffing Trends (Full Time Equivalent (FTE)/Work Year Equivalent (WYE) plan vs. actual)

This set of indicators was selected based on work done by the International Council on Systems Engineering, a NASA cross-agency working group, and a validating survey performed in 2019 across selected NASA programs and projects. The remaining sections of this guide will describe each of these indicators in detail.

2.0 Introduction

2.1. What Is a Leading Indicator?

A leading indicator is a measure for evaluating the effectiveness of how a specific activity is applied on a program in a manner that provides information about impacts likely to affect the system performance objectives. A leading indicator is an individual measure or collection of measures that predict future performance before the performance is realized. The goal of the indicators is to provide insight into potential future states to allow management to act before problems are realized. (See Reference 1.)

So, a leading indicator is a subset of all the parameters that might be monitored on a program or project that has been shown to be more predictive as far as impact to performance, cost, or schedule in later life cycle phases. They are used to determine both the maturity and stability of the design, development, and operational phases of a project. These indicators have been divided into two types: Technical Leading Indicators (TLI), which apply to the technical aspects of a project, and the Programmatic Leading Indicators (PLI), which apply to the more programmatic aspect. The TLIs may be a subset of or in addition to the set of Technical Performance Measures (TPM) that may be unique to a program/project. According to the International Council on Systems Engineering (INCOSE), the definition of a TPM is a measure used to assess design progress, compliance to performance requirements, and technical risks. TPMs focus on the critical technical parameters of specific system elements. They may or may not be predictive in nature. For additional information on TPMs, see NASA/SP-2016-6105 "NASA Systems Engineering Handbook," Section 4.2.

2.2. How Are They Used?

As shown in Figure 2-1, leading indicators are used throughout the program/project life cycle. However, any one indicator may be useful only during a few of the phases. For example, verification trends are useful only during the times leading up to and during the phases in which the product is verified. Also, note that the leading indicators may exist first in an estimated form and then, as more information becomes available, they may be refined or converted into actual measured values. For example, early in Pre-Phase A the number of requirements can be estimated and tracked. As the set of requirements is being defined in Phase A, they can be counted and the actual number can replace the estimated values in the indicators.

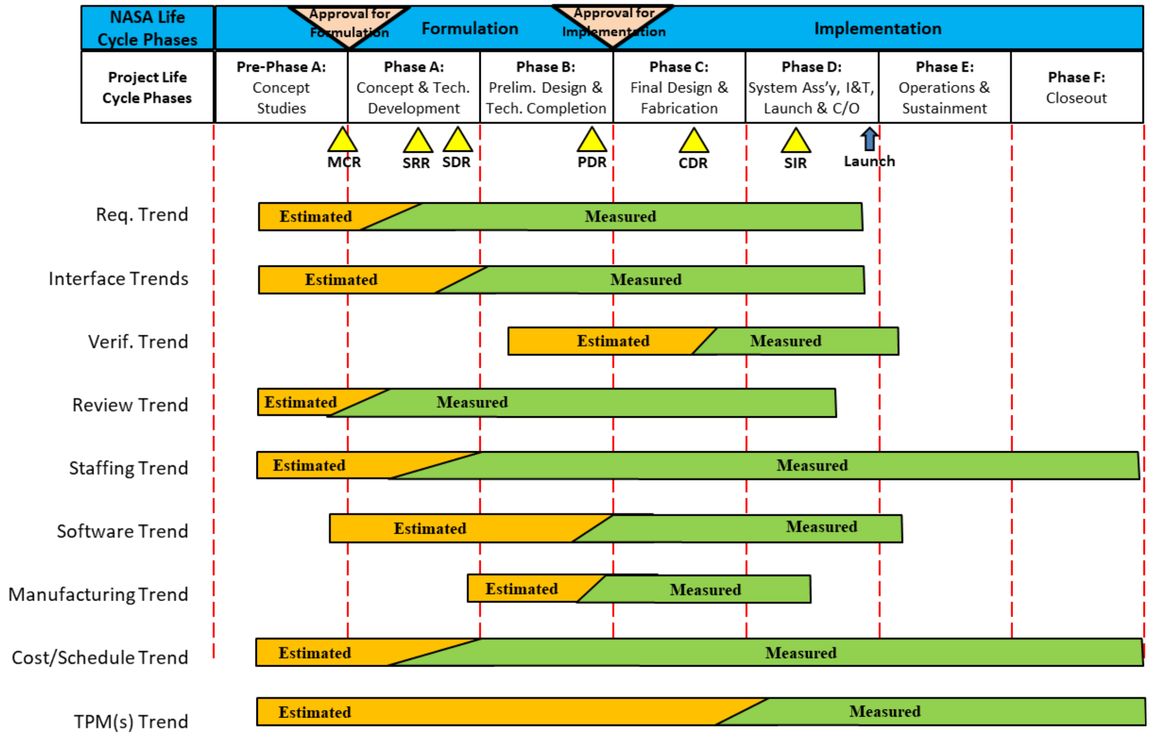


Figure 2-1 Use of Leading Indicators Throughout the Life Cycle

Leading indicators are always viewed against time to see how the measure is progressing so that the product's stability and maturity can be determined. This may be depicted in tabular form or perhaps more usefully in graphical form. The parameters also may be plotted against planned values and/or upper or lower limits as shown in Figure 2-2. These limits, if used, would likely be defined by the program/project based on historical information.

By monitoring these trends, the program or project managers, systems engineers, other team members, and management can more accurately assess the health, stability, and maturity of their program/project. Trend analysis can help predict future problems that might require attention and mitigation before they become too costly. How often these parameters should be measured and tracked will depend on the length, complexity, and size of the program/project. The updated measurements may be provided weekly, monthly, or quarterly. It is recommended that measurements be taken at least quarterly. However, this may be too long a period for some projects to catch potential problems in a timely manner. The interval of measurement for each of the indicators should be identified early in the planning phases and noted in the Program/Project Plan or other documentation.

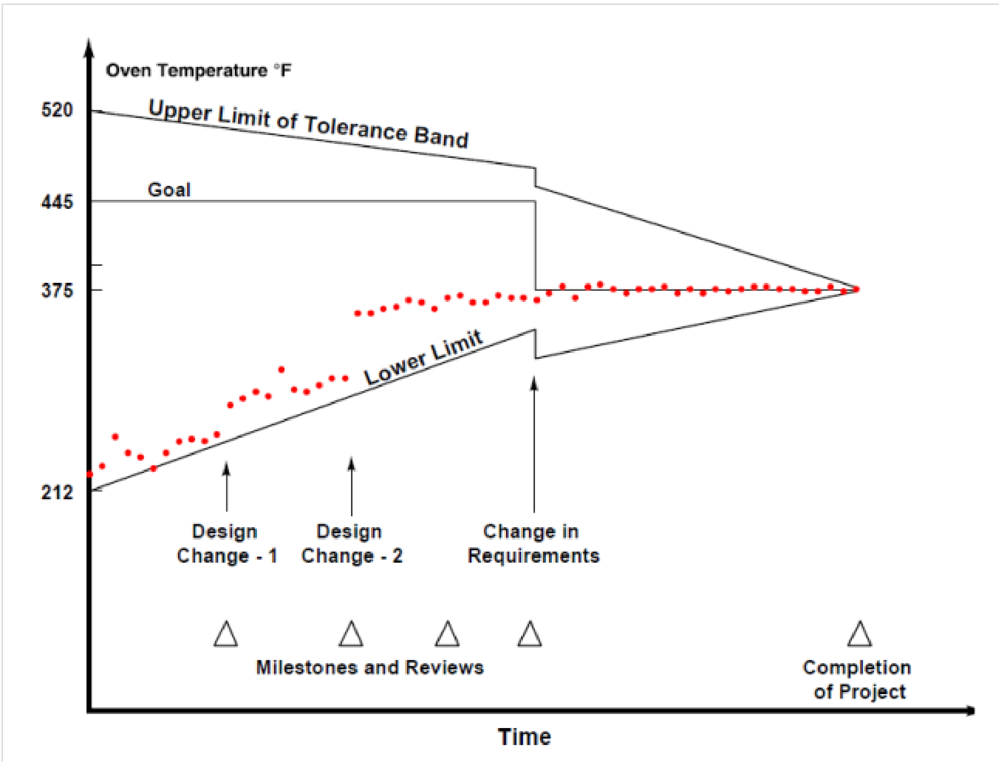


Figure 2-2 Example Trend Plot from BAE Presentation "Technical Performance Measure," Jim Oakes, Rick Botta, and Terry Bahill

By combining these periodic trending indicators with the life-cycle review entrance and success criteria, the program/project will have better insight into whether their products are reaching the right maturity levels at the right points in the life cycle, as well as an indication of the stability of the program/project. The entrance criteria, in particular, address the maturity levels of both the end product as well as the project documentation that captures its design, development, planning, and risks. However, just looking at maturity levels is not sufficient. If, for example, the product is appropriately designed to a Critical Design Review (CDR) maturity level but there are still significant changes in the requirements, the project cannot be considered stable. An evaluation of the aggregate set of indicators is needed to develop an overall understanding of both the maturity and stability of the program/project.

3.0 Common Technical Leading Indicators

A recommended set of common Technical Leading Indicators (TLI) are described in this section. The common Programmatic Leading Indicators (PLI) are described in Section 4.0. Each section discusses applicable trend categories, explaining why trends in each category are important and describes the specific trend measurements that need to be monitored. Each measurement is described, and sample plots shown. Note that these are only examples. These indicators may be portrayed by the project in the format that is most useful to the project. The complete set of Common Technical Leading Indicators is presented in Appendix C along with the minimum characteristics for the displays. As long as the minimum set of plotting characteristics is satisfied, how the project chooses to depict the trend is left up to the project and its decision authorities.

3.1. Requirement Trends

This category includes three trends that should be monitored to assess the stability and maturity of the products: Percent Requirement Growth, To be Determined/To Be Resolved (TBD/TBR) Closures, and the Number of Pending Requirement Changes. Each is separately discussed in the following sections.

3.1.1. Why Are the Leading Indicators Important?

Controlling the growth of requirements is one of the best ways to reduce unplanned cost and schedule delays later in a project life cycle. For each new requirement that is added, dozens more may be derived as the project moves deeper into the product hierarchy. Each of these new and derived requirements will then need to be verified, again potentially adding more cost and schedule time. Therefore, creating or defining new requirements must be performed with care. Ensure that each requirement is truly "required" and not just a desire or wishful thinking. Requirements should convey only those things that absolutely must happen to produce a product that will accomplish the desired outcome. They should not dictate a single solution nor strangle the creativity of the designer. The requirement set should allow for multiple design options that can then be traded against key parameters such as performance, cost, and schedule.

Depending upon where the project is in the life cycle, requirement growth is not necessarily a bad thing. During Phase A, the project moves from having no requirements to the formal definition of the requirements culminating with the System Requirement Review (SRR). So naturally, there should be a drastic increase in requirements. Also within phase A is the System Definition Review (SDR) at which the architectures are presented. It is also expected that there may be additional requirements defined during this part of the life-cycle phase.

As the project moves to Phase B and the Preliminary Design Review (PDR), the requirement growth or velocity should be significantly slowed but realistically may see some small growth as the designs are prototyped, gaps in the requirement set are found, unforeseen need for a requirement is identified, etc. As the project moves into Phase C and the Critical Design Review (CDR) and the product design is finalized, requirement growth should be very small. The later requirements are added to a project, the more difficult they may be to enact and the more cost and schedule they may be adding. As the project completes Phase

C, culminating with the System Integration Review (SIR) and moves into Phase D, requirements growth should be virtually zero. Adding significant requirements at this point will likely mean scrapping previously designed parts and starting a redesign cycle.

3.1.2. Percent Requirement Growth Trend Description

This indicator provides insight into the growth trend of the program/project's requirements and their stability. Requirements growth, sometimes called "requirements creep," can affect design, production, operational utility, or supportability later in the life cycle. For each requirement added, there is a corresponding cost of time and schedule involved for its handling, maintenance, and verification. The basic question being answered by this indicator is "Is the program/project effort driving towards requirements stability?"

Base measurement for this indicator is the total number of requirements in each of the program/project's requirement documents. The program/project first determines where all its requirements are located and how far down within the product hierarchy the requirements will be tracked. For example, there may be several layers of requirements as they flow down to systems, subsystems, elements, assemblies, and components within the overall project. Some requirements will be the responsibility of the NASA program/project team; some requirements may be the responsibility of a contractor or vendor. The program/project will need to decide how far down it is practical to determine this metric. How far down they will be tracking requirements should be part of the discussion in their Formulation Agreement and/or Program/Project Plan on how they will provide this indicator.

Since most program/projects use a tool to help keep track of their requirements (Cradle, DOORS, Excel spreadsheet, Word document, etc.), counting should be a simple matter of asking the application they are being stored in how many there are or how many times the word "shall" appears in their document. This can be automated in many cases. This assumes that the program/project is following good requirements definition practices of only using "shalls" to define a requirement and that there is only one "shall" per requirement. The practice of having one sentence with a "shall" to introduce a number of requirements (e.g. "The product shall perform the following characteristics: a. Breathable atmosphere for 30 days b. continuous pressure of 8.1 psia, etc.) is not used or if it is used that each of these obscured requirements is numbered. A spreadsheet that keeps track of these measurements might be as shown in the first and second column of Table 3-1 (the third column will be discussed in the next section). This would be a representation for a snapshot of the number of requirements on a certain date. Other snapshots would be taken periodically and results tracked over time.

Table 3-1 Simple Snapshot Requirement Tracking Spreadsheet

Document	Date	# Req	# TBD/ TBRs
PRD	xx/xx/xx	90	5
SRD	xx/xx/xx	150	8
SSRD 1	xx/xx/xx	300	15
SSRD 2	xx/xx/xx	200	10
ICD 1	xx/xx/xx	25	5
ICD 2	xx/xx/xx	53	20
ICD 3	xx/xx/xx	16	3
Total		834	66

The first column lists the documents within the project that contain requirements. The project has decided to track requirements at the project, system, subsystem, and ICD level (more about ICDs will be discussed in later sections). The second column captures what date the count was taken, and the third column captures how many requirements were in the document at that date. This information would be taken periodically at an interval that makes sense for the program/project. It must also be decided whether to track the requirements at the individual document level and/or in total of all the documents. Again, this strategy should be included in the Formulation Agreement or Program/Project Plan.

As these requirement snapshots are built up over time, they can then be tabularized and plotted. Figure 3-1 is a simple plot of requirements using raw number of requirements—this could be per document or as a total for the project. For this type of graph, it is not the raw number of requirements that is of interest (large projects may have many requirements while small project may have few), it is the shape of the curve that indicates how the number is growing or has become stable. It is useful to include notes about unusual characteristics on the graph—in this case a requirement scrub activity was noted to bring the number of requirements back into control. It is also good to put key milestones such as life-cycle reviews, on the graph so that the data can be evaluated within context.

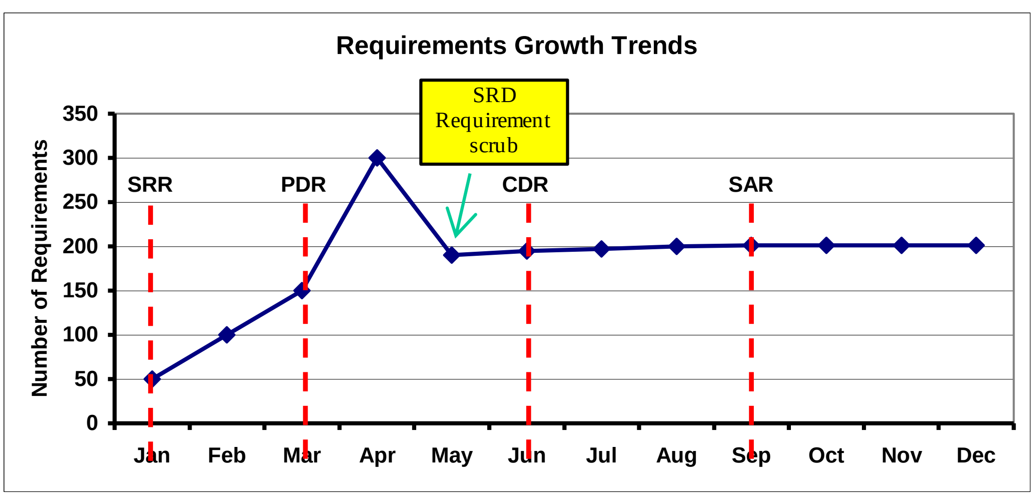


Figure 3-1 Simple Requirements Growth Plot – Raw Count

Another way of plotting this information is in the percentage of growth since the last measurement period. Table 3-2 shows an example spreadsheet for the requirements within a single document, say SSRD1 from the above spreadsheet.

Table 3-2 Simple Spreadsheet for Percent Requirements Growth

Date	# Req	% Req Growth
2/1/2011	92	0%
3/1/2011	96	4%
4/1/2011	115	20%
5/1/2011	150	30%
6/1/2011	110	–27%
7/1/2011	112	2%
8/1/2011	113	1%
9/1/2011	115	2%
10/1/2011	80	–30%
11/1/2011	80	0%
12/1/2011	80	0%

The percent growth is calculated by subtracting the number of requirements on a date from those on its previous date and dividing by the number of requirements on the previous date and then multiplying by 100 (e.g., (96-92)/92 x 100 = 4%). When plotted the data would look like Figure 3-2:

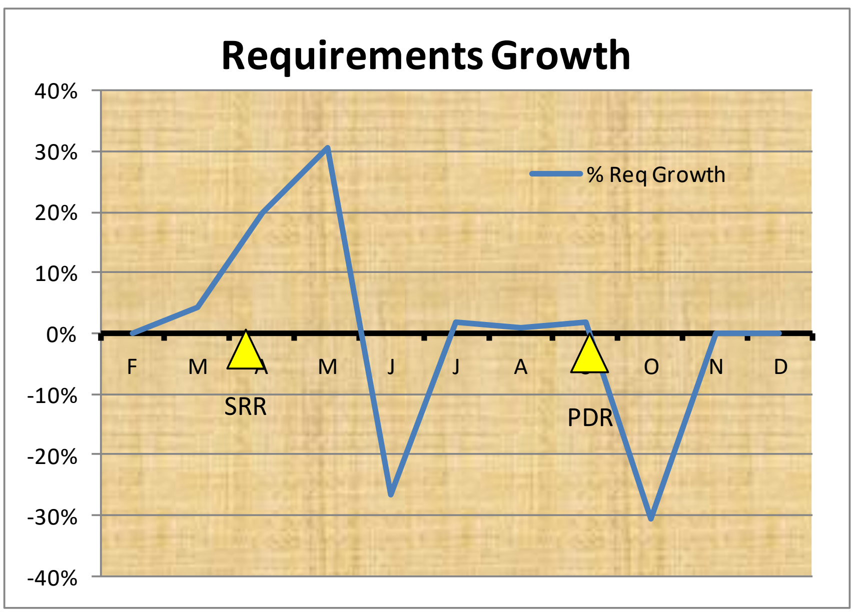


Figure 3-2 Simple Requirements Growth Plot

As can be seen, the requirements were growing up through SRR as expected, but then continued to grow thereafter. At some point a requirements scrub took place and so the requirements growth went negative and then stabilized until just after PDR when some requirements were deleted and then remained stable again.

So the question is—is this a "good" project or not? In the ideal model, requirements would grow through SRR at which time all requirements would be perfectly defined and then growth would be zero thereafter. In the real world, this rarely happens. As concepts are refined, designs deepened, and the realities of the political and budgetary changes affect the projects, it is customary to see requirements grow and ebb. After SRR, it is always desirable to keep requirements growth to a minimum, but some change is to be expected. It is clear that in the project example shown in Figure 3-1, requirements have continued to grow well after PDR. This should trigger a flag that a closer look at the requirements situation is warranted. This might be completely explainable but at least the trend would indicate that more attention might need to be paid to the situation. As historical data is gathered across multiple projects, guidelines or upper/lower boundary conditions can be developed against which this data could be plotted. Some Centers or projects may already have this type of boundary information available and if so, plotting against predictions or plans would be very useful.

3.1.3. TBD/TBR Closures Trend Description

As noted in Table 3-1, another useful indicator is the number of "to be determined" (TBD) or "to be resolved" (TBR) requirements within each document. TBDs/TBRs are used whenever the project knows they need a requirement for some performance level but may not yet know exactly what that level is. Typically, a TBD is used when the level has not been determined at all, whereas a TBR is used when a likely level has been determined but further analysis or agreements need to be obtained before setting it officially as the requirement level. Additional analysis, prototyping, or a more refined design may be required before this final number can be set. As the project moves later in the life cycle, remaining TBDs/TBRs hold the potential for significant impact to designs, verifications, manufacturing, and operations and therefore present potentially significant impacts to performance, cost, and/or schedule.

Typically, this indicator is viewed as a "burndown" plot, usually against the planned rate of closures. An Example is shown in Figure 3-3.

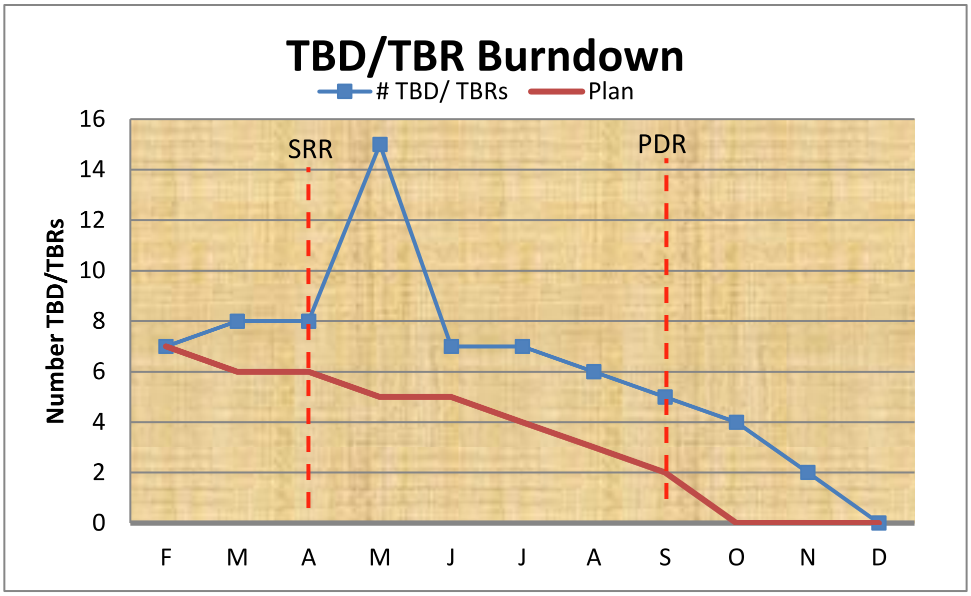


Figure 3-3 TBD/TBR Burndown

3.1.4. Number of Pending Requirement Changes Trend Description

In addition to the number of requirements that are already in the program/project documentation, there are usually a number of potential changes that may be working their way through the requirements management process. Keeping up with this bow wave of potential impacts is another way of analyzing the requirements indicator trend. The number of pending change requests can be plotted along with the previous requirement trend graphs as shown in Figure 3-4.

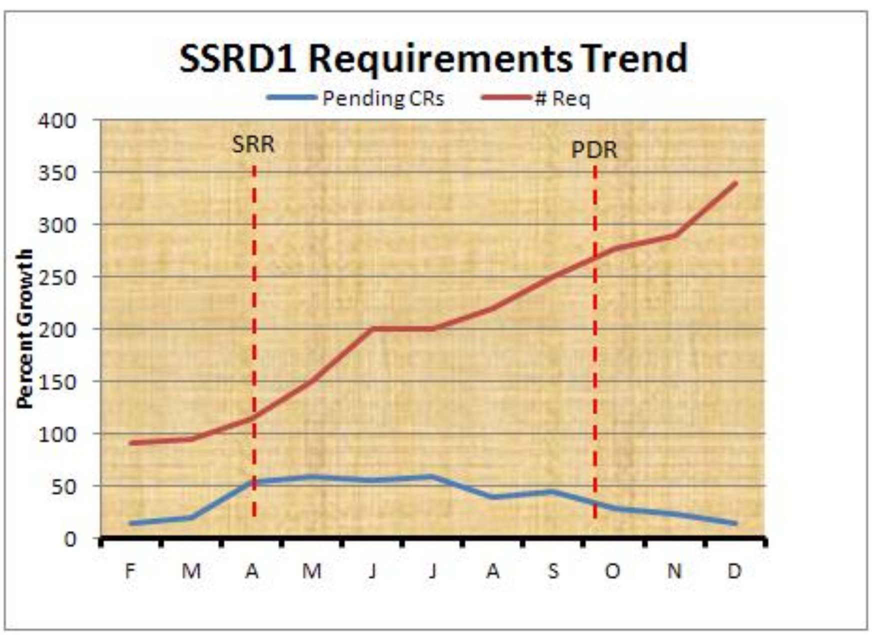


Figure 3-4 Pending Requirement Change Requests

The program/project may elect to keep track of additional information. One useful indicator is the reason for the change—is it a new requirement that is being driven by sources external to the project and therefore not within their control? Is it driven by the customer adding new requirements and therefore the customer should expect a potential increase in cost and/or schedule? On the other hand, is it a requirement that the project just missed or did not realize they needed and therefore represents an internal change that may need to be justified to the customer (especially if it involves a cost/schedule increase)? Table 3-3 shows a more complete spreadsheet that keeps up with this rationale as well as the previous spreadsheets for number of requirements, number of TBD/TBRs, and the percent growth indications.

Table 3-3 Requirement Changes and Reason

Date	# Req	# TBD/ TBRs	% Req Growth	% TBD/TBR Growth	No. Req Changes	Reason		
						External	Customer	Internal
2/1/2011	92	7	0%	0%	0	0	0	0
3/1/2011	96	8	4%	14%	4	2	1	1
4/1/2011	115	8	20%	0%	19	5	5	9
5/1/2011	150	15	30%	88%	35	1	7	27
6/1/2011	110	7	– 27%	–53%	–40	0	20	20
7/1/2011	112	7	2%	0%	2	0	1	1
8/1/2011	113	6	1%	–14%	1	1	0	0
9/1/2011	115	5	2%	–17%	2	0	0	2
10/1/2011	80	4	–30%	–20%	–35	15	5	15
11/1/2011	80	2	0%	–50%	0	0	0	0
12/1/2011	80	0	0%	–100%	0	0	0	0

A snapshot plot of this information could be generated as shown in Figure 3-5 or a trend line graph developed as shown in Figure 3-6. There are many ways to represent this information.

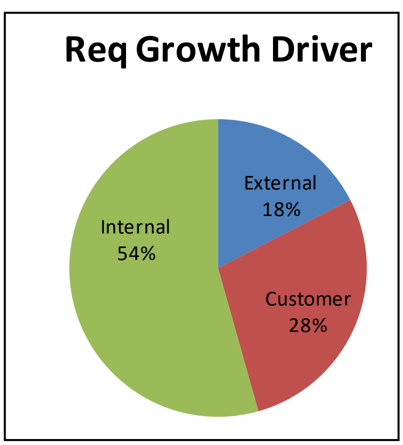


Figure 3-5 Change Source Snapshot

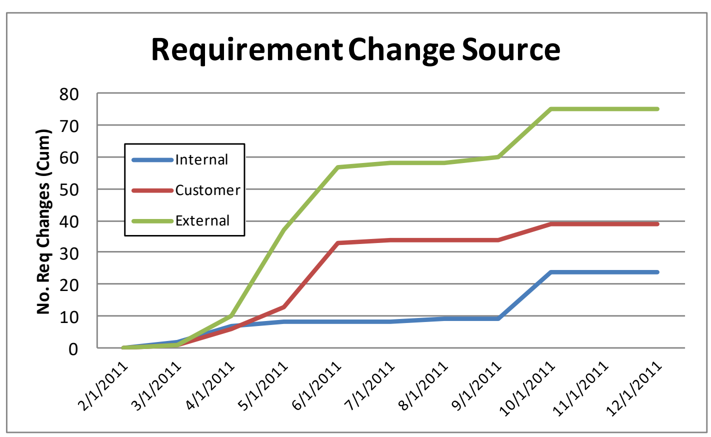


Figure 3-6 Change Source Trend

Some projects may want to maintain additional information about each requirement change, such as the cost and schedule impacts. Table 3-4 is an example of additional information that may be useful.

Table 3-4 Additional Data for Understanding Requirement Changes

Require-ment	Req. Change			Impact		Reason			Status
	Added (New)	Deleted	Modified	Cost	Sched	External	Customer	Internal	
SRD # 42	X			$3M	6 mo.		X		Approved
ICD 1004 Req. 14.1		X		– $90K	– 8 mo.			X	Pending
PRD Req. 45			X	0	0	X			Approved

3.2. Interface Trends

This category of trends includes the percentage of ICDs that have been approved, the burndown of TBDs/TBRs within those documents, and the number of interface change requests.

3.2.1. Why is the Leading Indicator Important?

This indicator is used to evaluate the trends related to growth, stability, and maturity of the definition of system interfaces. It helps in evaluating the stability of the interfaces to understand the risks to other activities later in the life cycle. Inadequate definition of the key interfaces in the early phases of the life cycle can drastically affect the ability to integrate the product components in later phases and cause the product to fail to fulfill its intended purpose. The longer these interfaces are left undefined, the more likely problems will occur and therefore negative impacts to performance, cost, and schedule.

Interface requirements may be contained in various documents depending upon the program/project. Some program/projects will define them at a high level in an Interface Requirements Document (IRD). These may be taken by the subsequent engineering teams, (often a prime contractor, or vendor) to be further detailed as an ICD. If a program/project is interfacing to a legacy system, they may be working to what is often called a “one-sided ICD” or an Interface Definition Document (IDD). Other programs/projects may put the high level and/or detailed interface requirements and agreements into other documents. For simplicity, the term ICD will be used here, but it is intended to be whatever document(s) contain the interface requirements and definitions for the program/project.

Note that the requirements within the interface documents as well as the number of requirement TBDs and TBRs need to be included with the overall requirement trend as discussed in section 3.1.1. However, the program/project may also choose to account for the interface-related requirements trends separately from the non-interface related requirements due to their importance. How the accounting is made needs to be clear in the Formulation Agreement and/or Program/Project Plan.

3.2.2. Percent ICDs Approved

The program/project will need to identify how many documented interfaces it needs both between elements within their system as well as to the interfacing elements external to their product. Once the total number of interface documents has been identified, this indicator will reflect trends in their approval. One way of capturing where interfaces exist within a system, what kind of interfaces they are (bottom left half) and where the interface definition and requirements are documented (upper right half) is shown in Table 3-5.

Table 3-5 Example Matrix for the Identification of Interfaces for a Program/Project

ICDs	Element 1	Element 2	Element 3	Element 4	Element 5
Element 1		ICD 1	ICD 2		ICD 3
Element 2	Data, Fluid			Drawing 1	
Element 3	Power	None			IDD 1
Element 4	None	Data	None		
Element 5	Data, Power	None	Fluid, Power	None	

Once the interfaces are determined, a program/project can track how many of them have been developed and approved. For programs/projects with few interfaces, this can be done in a tabular form as shown in Table 3-6 for example. Programs/projects with many interfaces may want to display the trend graphically as shown in Figure 3-7.

Table 3-6 Example of Tabular Tracking of Interface Documents

# ICDs	Planned	Actual	# Approved	# In work	# Not Started	% Approved	% In work	% Not Started
2/1/2019	7	7	0	1	6	0%	14%	86%
3/1/2019	7	9	0	2	7	0%	22%	78%
4/1/2019	7	12	0	3	9	0%	25%	75%
5/1/2019	8	12	0	5	7	0%	42%	58%
6/1/2019	8	13	0	7	6	0%	54%	46%
7/1/2019	9	13	1	7	5	8%	54%	38%
8/1/2019	9	15	3	7	5	20%	47%	33%
9/1/2019	9	15	7	6	2	47%	40%	13%
10/1/2019	9	15	8	5	2	53%	33%	13%
11/1/2019	10	16	10	4	2	63%	25%	13%
12/1/2019	10	16	12	3	1	75%	19%	6%

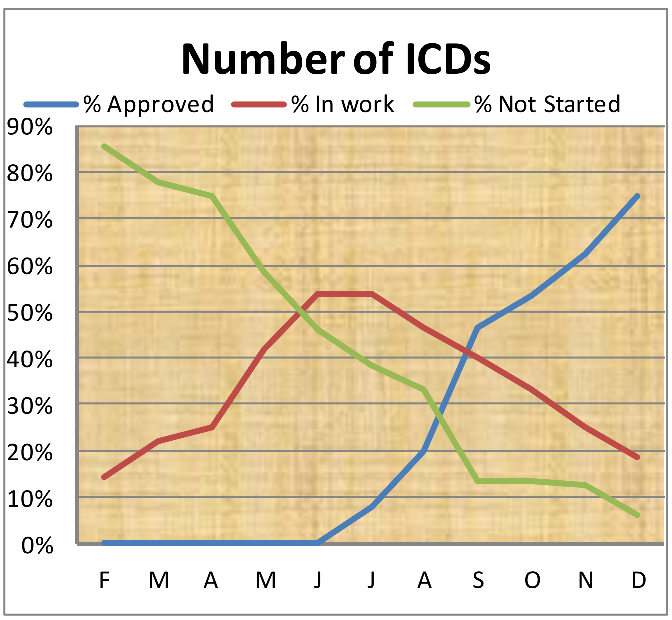


Figure 3-7 Example Plot Trending Interface Documentation

3.2.3. ICD TBD/TBR Burndown

In addition to the requirements TBD/TBRs that are discussed in Section 3.1.3, there may be others within the interface documentation. This indicator will track them. The program/project may elect to lump them together with the requirement TBD/TBRs if desired. Similar tracking is done as for the requirement

TBD/TBRs in Section 3.1.3 and plotting the information can be made in several ways. A simple example is shown in Figure 3-8.

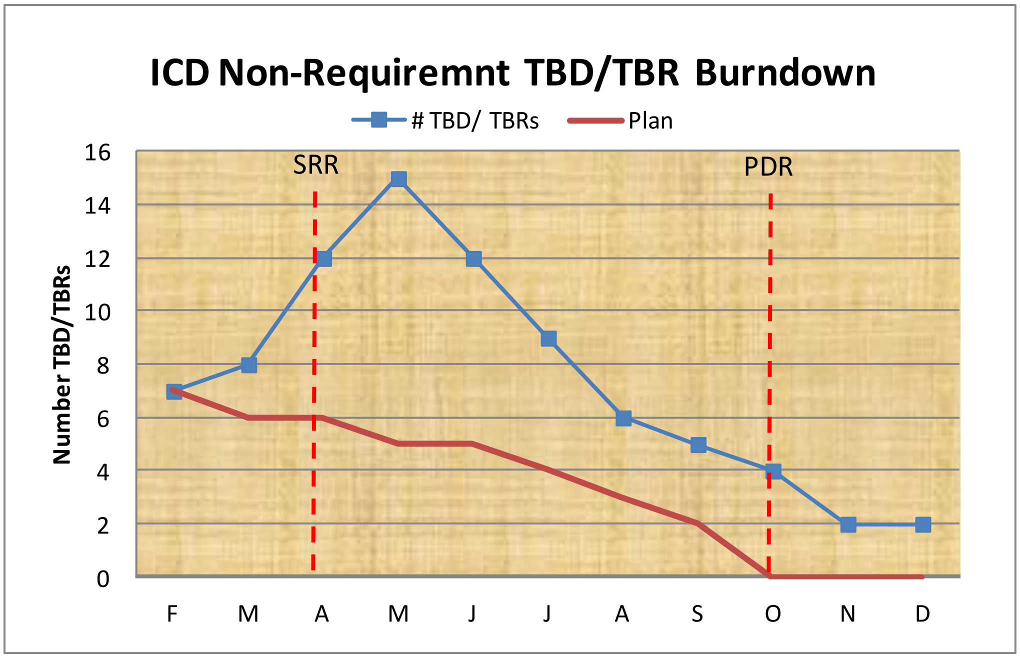


Figure 3-8 Example ICD Non-Requirement TBD/TBR Burndown vs. Plan

3.2.4. Number of Interface Change Requests

Similar to the need to track requests for changes to the program/project requirements, tracking change requests to the interface documentation is also an indication of a pending set of changes that might affect the future performance, cost, and schedule. As these changes come later in the life cycle, they may affect agreements or designs that have already started in the manufacturing process. Changes coming this late in the life cycle can affect many organizations, requiring redesign, scrapping of parts, and recertification.

Like the requirements change requests discussed in Section 3.1.4, similar information may be gathered about the interface change requests. For example, Table 3-7 shows an example of the information that might be gathered. In addition, the cost or schedule impact and status of the requests also may be gathered and plotted.

Table 3-7 Example Information for Interface Trending

Date	# I/F	# TBD/ TBRs	% Interfac	% TBD/TBR Growth	Delta I/F	Reason			Plan
						External	Customer	Internal	
2/1/2011	15	7	0%	0%	0	0	0	0	7
3/1/2011	15	8	0%	14%	0	2	1	1	6
4/1/2011	20	12	33%	50%	5	5	5	9	6
5/1/2011	30	15	50%	25%	10	1	7	27	5
6/1/2011	50	12	67%	-20%	20	0	20	20	5
7/1/2011	60	9	20%	-25%	10	0	1	1	4
8/1/2011	62	6	3%	-33%	2	1	0	0	3
9/1/2011	65	5	5%	-17%	3	0	0	2	2
10/1/2011	80	4	23%	-20%	15	15	5	15	0
11/1/2011	80	2	0%	-50%	0	0	0	0	0
12/1/2011	80	2	0%	0%	0	0	0	0	0

3.3. Verification Trends

Verification of a program/project's product is the proof of compliance with its requirements. This is done through test, analysis, demonstration, or inspection. Each requirement will need to be verified through one or more of these methods. This category includes two indicators: verification closure burndown and the number of deviations/waivers requested as a result of the verification activities.

3.3.1. Why is the Leading Indicator important?

Tracking which requirements have and have not been verified can be accomplished through various means as appropriate for the size and complexity of the program/project. Complex programs/projects may use a tool such as CRADLE or DOORs, others may use spreadsheets or word documents. Whatever method is chosen, it is important to know which requirements have been verified (i.e., "closed") and which are still to be verified ("open"). This can be indicated by flags or other indicators within a selected tracking tool, using separate Verification Closure Notices (VCN), or other means chosen by the program/project.

Leaving verification closure too late in the life cycle increases the risk of not finding significant design issues until the cost of correcting them is untenable. Often, this means additional cost and schedule to correct the problems or having to work around the problems through more complex operational scenarios.

3.3.2. Verification Closure Burndown

This indicator tracks the closure of the requirement verifications as an indication of project maturity and stability. Table 3-8 is an example of the parameters a program/project may track over time. This information can be displayed graphically as either numbers or percentages of open verifications. It is useful to plot them against a predicted or planned rate of closure for better insight as shown in Figure 3-8.

Table 3-8 Example Matrix for Tracking Verification Closure Burndown

Date	# Verif	open verif.	Closed verif.	% Open verif.	# Planned Open verif.	% Planned Open verif.	# Waivers
1/1/19	90	90	0	100%	**90**	100%	0
2/1/19	90	88	2	98%	85	94%	0
3/1/19	100	90	10	90%	75	75%	3
4/1/19	100	75	25	75%	55	55%	3
5/1/19	100	65	35	65%	45	45%	5
6/1/19	100	50	50	50%	30	30%	7
7/1/19	100	45	55	45%	20	20%	10
8/1/19	100	40	60	40%	10	10%	20
9/1/19	100	25	75	25%	5	5%	25
10/1/19	100	10	90	10%	0	0%	30
11/1/19	100	0	100	0%	0	0%	35
12/1/19	100	0	100	0%	0	0%	35

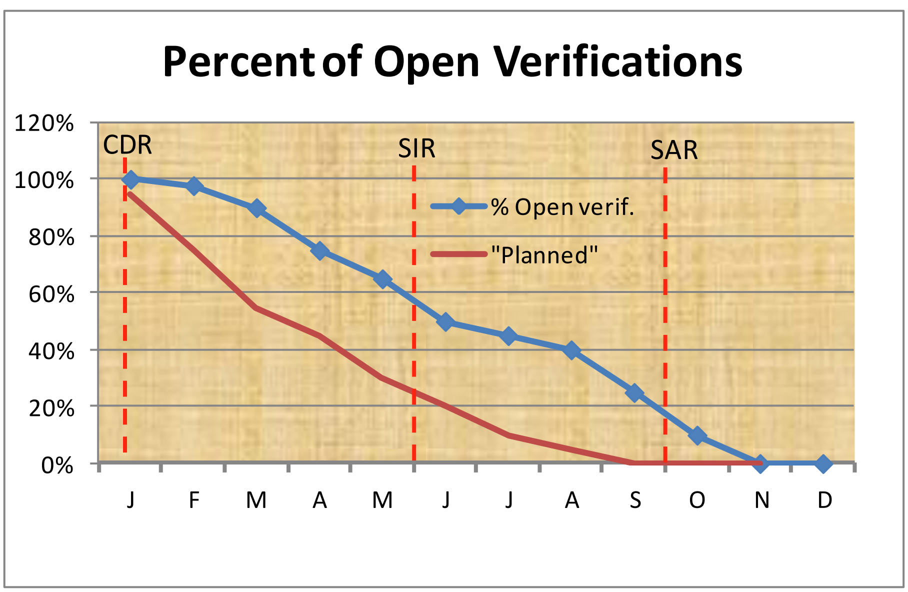


Figure 3-8 Example Plot of Verification Burndown

3.3.3. Number of Deviations/Waivers Approved/Open

A waiver or deviation is a documented agreement intentionally releasing a program/project from meeting a requirement. The standard definition of a deviation is alleviating a program/project from a requirement before the set of requirements are baselined and a waiver is after the requirements are baselined. Some programs/projects make the distinction that a deviation is granted when the program/project is in the Formulation Phases (Pre-Phase A, Phase A, Phase A or Phase B) and a waiver when in the Implementation Phases (Phase C, D, E, or F). In either case, it is important to document and track both the approved and pending requests. Increasing numbers of deviations/waivers may indicate potential issues later in the life cycle as the product begins to vary from the set of requirements deemed necessary to satisfy the customer and other stakeholders.

Table 3-9 is an example spreadsheet of how these indicators might be tracked. The program/project may choose to gather and track other information about the waivers such as the reason, who submitted, cost if not approved, etc.

Table 3-9 Example Tracking of Approved and Pending Waivers

Date	# Verif	Open Verif	# Approved Waivers	# Waivers Pending
Date 1	90	90	0	0
Date 2	90	88	0	1
Date 3	100	90	3	3
Date 4	100	75	3	2
Date 5	100	65	5	4
Date 6	100	50	7	6
Date 7	100	45	10	14
Date 8	100	40	20	38
Date 9	100	25	25	35
Date 10	100	10	30	25
Date 11	100	0	35	15
Date 12	100	0	35	10

This information also can be plotted against the verification closures to give a more complete picture of the verification activities as shown in Figure 3-9. Figure 3-10 shows an example of another important parameter to track—the number of waivers/deviations that have been requested but not yet dispositioned (i.e., “pending”). This may represent a bow wave of waivers that could affect future cost and schedules.

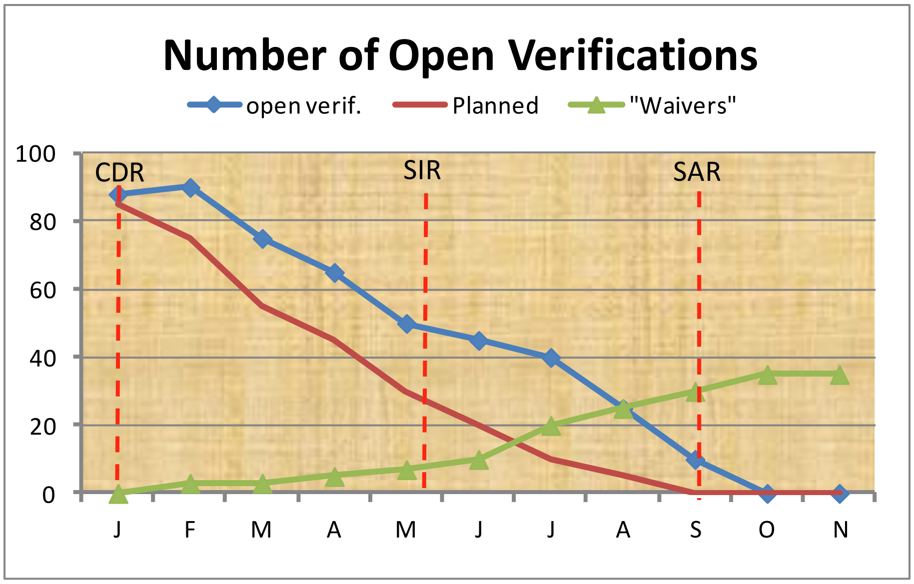


Figure 3-9 Example Plot of Waivers Granted and Verification Burndown

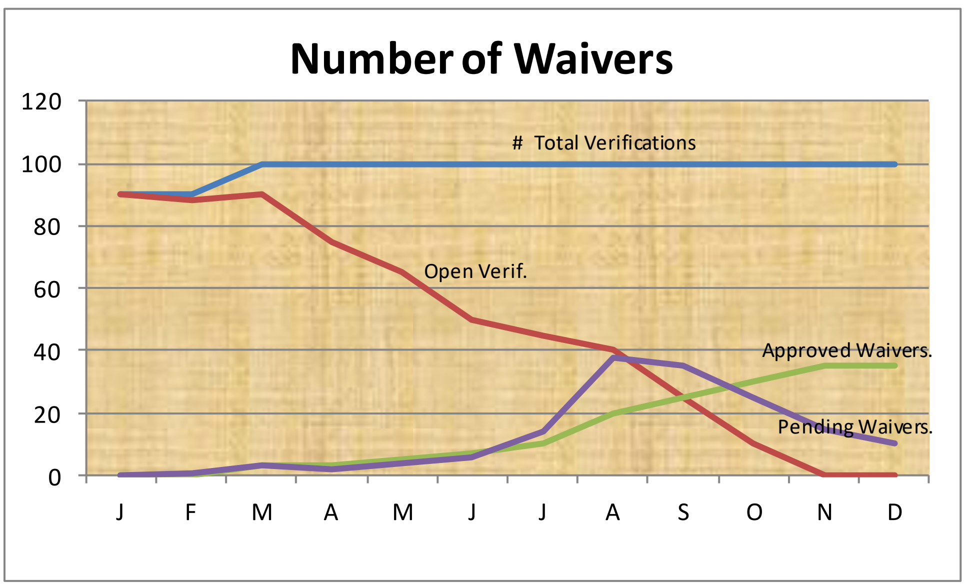


Figure 3-10 Example of Waivers Approved and Pending

3.4. Review Trends

This indicator tracks the activities resulting from a life-cycle review. Depending on the program/project, the items that are identified for further action by the reviewing body may be called Action Items (AI), Requests for Action (RFA), Review Item Discrepancies (RID) or other nomenclature. Whatever they are called, it is important to track their disposition and eventual closure. There is one indicator in this category: RID/RFA/AI burndown per review

3.4.1. Why is the Leading Indicator Important?

The purpose of a life-cycle review is to reveal the work of the program/project during that phase of the life cycle to a wider audience so that any issues, problems, design deficiencies, clarification of interpretations are presented and general buy-in by the stakeholders may be obtained. These comments (RFAs, RIDs, AI, etc.) are usually gathered and then dispositioned in some way. Some comments may not be valid or may be out of scope and so may be rejected. Some comments may be approved as is or modified in some way that is acceptable to both the submitter and the program/project. Those that are approved will need to be executed and the agreed-to work accomplished. At that point, the submittal is considered "closed."

While closing some comments may need to wait for a key triggering activity, not closing review comments in a timely manner may be pushing work off later and later in the life cycle where its implementation could have a cost and schedule impact. Critical design issues may be dragging on, which could affect subsequent design, manufacturing, testing, and/or operational activities. While some of these issues may be very tough and contentious, it is always better to face them as early as possible and drive to an agreed-to solution.

Note that another related indicator, life-cycle review date slippage, is addressed in the Schedule Trend section with the life cycle being one of several key milestones. (See Section 4.2.)

3.4.2. RID/RFA/Action Item Burndown per Review

This indicator is required per NPR 7123.1. Table 3-10 shows an example spreadsheet that is tracking the number of RID/RFA/AIs for a given life-cycle review. Note this measure is gathered periodically, in this case quarterly, not just at the next life-cycle review. Trending works best if the measurements are taken regularly.

Table 3-10 Number of Open RFAs/RIDs/AIs per Review

Date	MCR	SRR	PDR
Total	**35**	**40**	**55**
FY16Q1	30		
FY16Q2	25		
FY16Q3	20		
FY16Q4	10	40	
FY17Q1	5	30	
FY17Q2	2	20	
FY17Q3	0	15	
FY17Q4	0	12	50
FY18Q1		10	45
FY18Q2		8	40
FY18Q3		6	30
FY18Q4		4	25
FY19Q1		2	20
FY19Q2		2	15
FY19Q3		2	12
FY19Q4		2	10

This information perhaps can be better seen graphically. Figure 3-11 is an example.

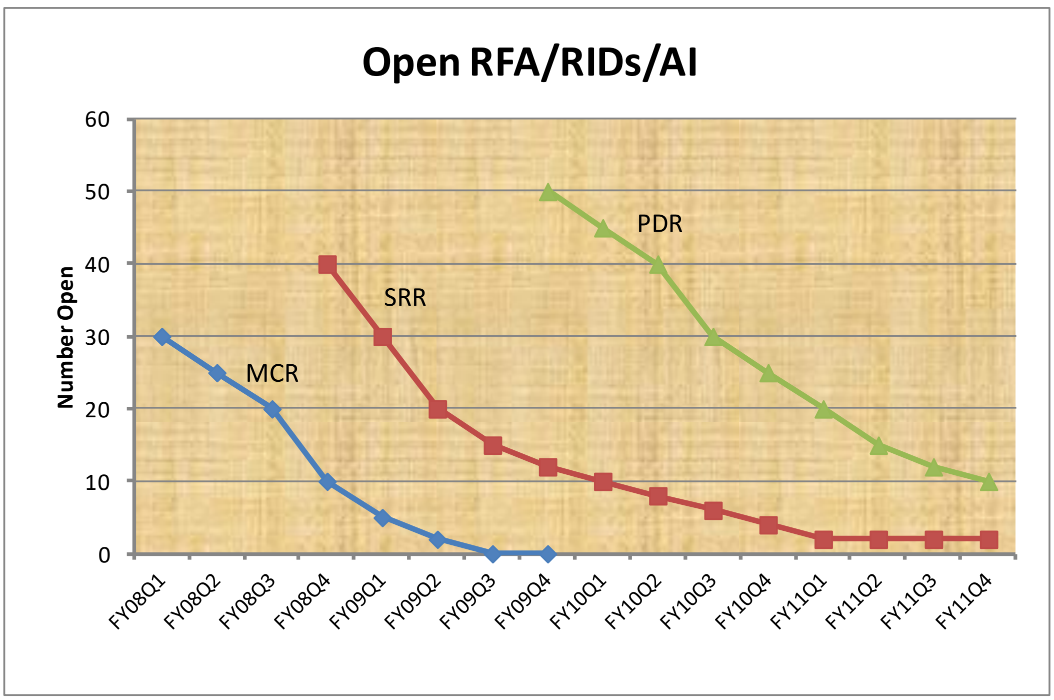


Figure 3-11 Number of Open RFAs/RIDs/AIs per Review

3.5. Software-Unique Trends

Software metrics or indicators are used to measure some property of a piece of software—its specifications, plans, or documentation. While Software Engineering has a rich history and large potential selection of measures, the single software metric “Number of Requirements/Features per Build/Release versus vs. Plan” continues the emphasis on requirements compliance measurement early in the program/project life cycle when it can be of maximum benefit and cost-effectiveness.

3.5.1. Why is the Leading Indicator Important?

This measure is used to evaluate the trends in meeting the required characteristics or features of a specific software build or release and the overall build/release development plan. Failure to meet the planned features of a build or release may indicate the inability to support the required development, analysis, verification, and testing of dependent hardware, software, or systems or of larger, more complex tasks ahead. A common occurrence on software projects in trouble is inability to meet the requirements and features of planned builds/releases and deferral of requirements and verifications to later builds/releases. This metric reveals program/project risk in terms of rework, infeasible schedule, and deferred work to later builds/releases. It can also mean several other things: the Program/Project may not have planned well and does not have the productivity they expected; they may be having staffing problems and can't make their schedules; some of the requirements may still be TBD or unclear or they may be having difficulty implementing some of them; they could be waiting on hardware deliveries, etc.

3.5.2. Number of Requirements/Features per Build/Release vs. Plan

This metric/indicator provides a quantitative measure of the number of requirements or features in a build vs. the number of requirements or features that were planned.

It is illustrated by counting the total number of requirements or features that were planned for each build/release, counting the total number of requirements or features that were actually included in the build/release, and then comparing the two to show how well the plan is being met by the development effort. They can also be linked to major system or software milestones to suggest the overall impact to the program/project/system.

A simple illustration of this is shown in Table 3-11.

Table 3-11, Table of Plan vs. Actual Requirements/Features by Build/Release

Build No.	# Planned Features	# Features in Build
0.5	15	10
1.0	50	45
1.1	120	100
1.2	300	230
1.3	300	300
1.4	400	389
1.5	440	415
2.0	600	500
2.1	650	560
3.0	700	610

Another approach is a more graphic software build trend histogram illustrated in Figure 3-12.

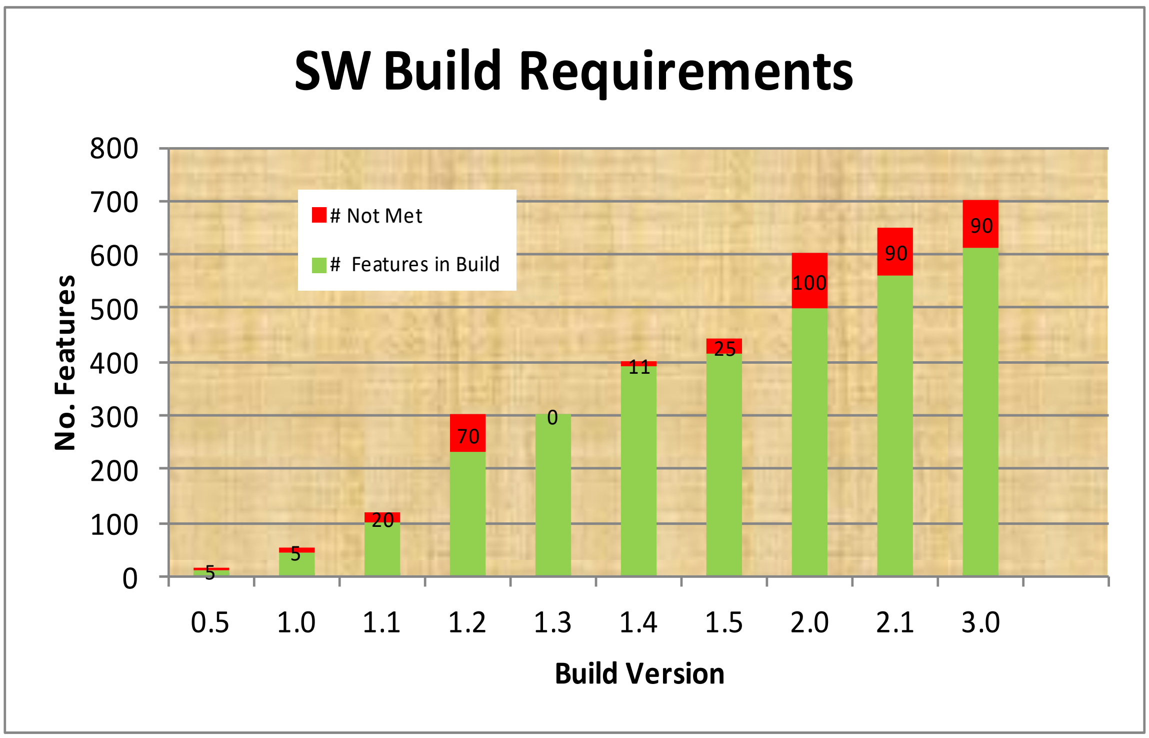


Figure 3-12 Software Build Trend Histogram

Another method of displaying this indicator is shown in Figure 3-13, which links the parameter to program/project milestones and build version numbers.

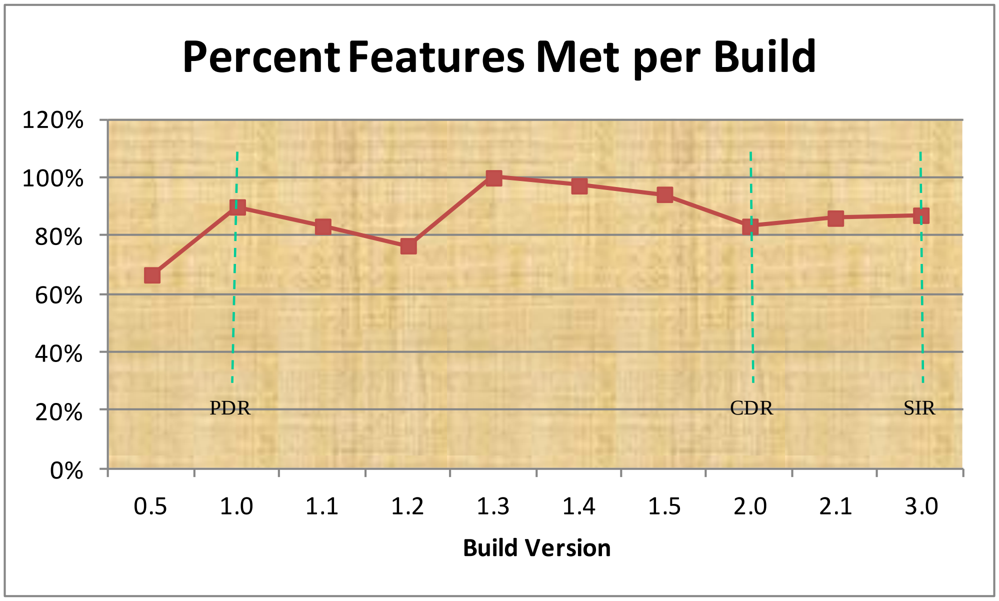


Figure 3-13 Percent Features Met per Build Version

3.6. Problem Report/Discrepancy Report Trends

Programs and projects conduct verification, validation, and quality control activities during the implementation life-cycle phases to ensure requirements and stakeholder expectations will be satisfied in advance of launch or being sent into the field. Where possible and determined practical, these activities are conducted in an environment as close to operational as possible, that exercise all the operational modes and scenarios as fully as possible, and that use the actual flight procedures and databases that will used during launch and operations. If during the conduct of these activities, the product fails to meet requirements or accepted standards, the problem is captured, reported to program/project management, and a corrective action or work around is developed. Depending on the Center, program, or project these problem identifications may be called problem reports or discrepancy reports.

3.6.1. Why is the Leading Indicator Important?

The systems that are built by NASA are often complex; distributed across people, organizations, and geography; implemented in multiple releases, builds, and patches; and affected by changes to baseline requirements approved by a configuration change board during the implementation phases. This demanding environment means that virtually no system is ever delivered without discrepancies, i.e., deviations from expected and/or required performance. The programs/projects are required to capture these discrepancies and compile the information so corrective action can be documented. When normalized against the project complexity, discrepancy reports can be used as a predictor of system performance. This leading indicator is applicable to both hardware and software projects.

In order to offer the most accurate predictor of future performance of the system being verified it is important that the discrepancy process be applied across all parties involved. This means both government and commercial suppliers should be required to participate in the process often requiring a single synchronized reporting timeline be used. Additionally, supporting information intended to characterize a discrepancy and document its history should be included in the regular reporting process.

3.6.2. Number of Discrepancy Reports (DRs) Open, Total Number of DRs

Depending on the specific project, there will be multiple types of discrepancy report information available for evaluation. Projects are encouraged to use this information to improve visibility into the actual condition of the system being developed. As a minimum, all projects should utilize a minimum of two data types in their regular reporting process: 1) number DRs/Problem Reports (PRs) open and 2) total number DRs/PRs.

This information is used to evaluate trends in the rate of closure and closure percentage of PRs and/or DRs. Large deviations for the planned closures of DRs/PRs vs. the schedule defined at the start to address them may be indicative of:

- <u>Work not being completed as planned</u> – in certain cases, the project team may be focused on commitments to deliver new functionality and not have the resources to address DR remediation in the workflow.
- <u>Low quality of re-work</u> – workmanship issues, problem parts, flawed fabrication steps are examples of problem sources that will result in frequent re-work despite the best efforts of a project to repair the problems the first time.
- <u>Insufficient resources</u> – Negative trends associated with DRs may be symptomatic of project resources becoming strained. This may be due to incorrect assumptions regarding the complexity of the solutions needed to resolve the problems; optimistic planning of workforce levels or workforce skill mix used to address the discrepancies found plus new ones entering the system; or insufficient resources (i.e., time and/or schedule) allotted for regression testing of fixes before the DR can be closed.

Figures 3-14 and 3-15 illustrate report formats that could be used to track project DRs and PRs. In preparing the specific format to be employed on the project, consider showing progress on closing PR/DRs vs. time, indicating key life-cycle milestones for reference, and including descriptions of these key milestones to ensure an accurate understanding across all stakeholders.

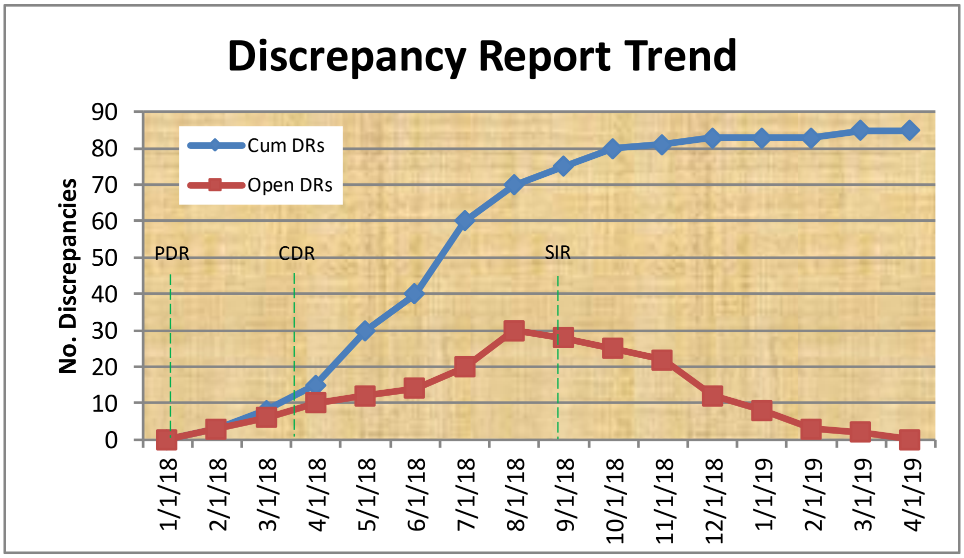


Figure 3- 14 DR/PR Closures Over Time

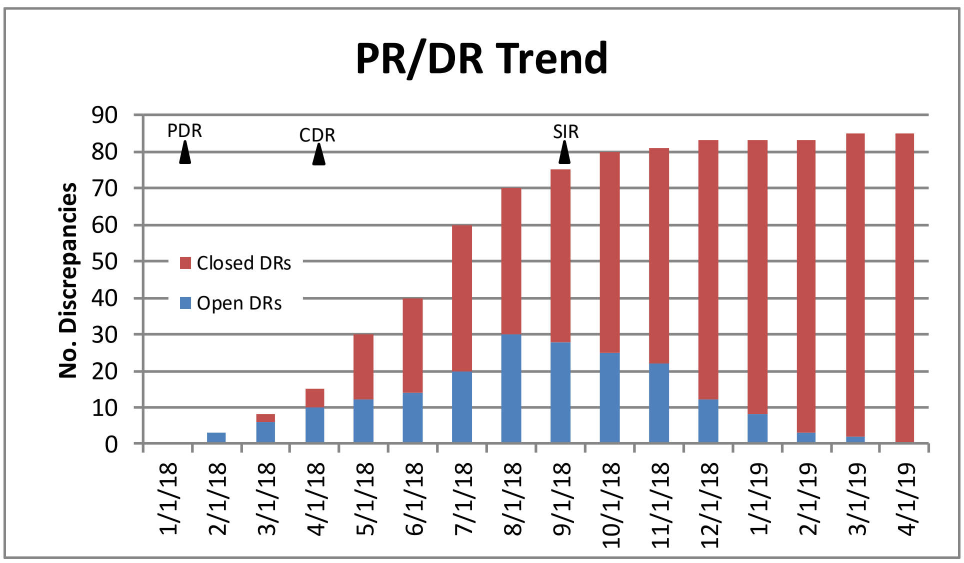


Figure 3-15 DR/PR Trend as Stacked Percentage

3.7. Technical Performance Measures

According to NPR 7123.1, TPMs are the set of critical or key performance parameters that are monitored by comparing the current actual achievement of the parameters to that anticipated at the current time and on future dates. They are used to confirm progress and identify deficiencies that might jeopardize meeting system requirements. Assessed parameter values that fall outside an expected range around the anticipated values indicate a need for evaluation and corrective action. There are two types of TPMs discussed in this section: the required common TPMs of mass margin and power margin and the other project unique TPMs (the selection of which will depend upon the type of product the program/project is producing).

3.7.1. Why is the Leading Indicator Important?

TPMs help the program/project keep track of their most critical parameters. These parameters can drastically affect the ability of the program/project to successfully provide the desired product. These indicators are usually shown along with upper and/or lower tolerance bands, requirement levels, and perhaps stretch goal indications. When a parameter goes outside of the tolerance bands, more attention may be required by the program/project to understand what is happening with that indicator and to determine if corrective action is warranted.

While there are a number of possible parameters that could be tracked in a project, selecting a small set of succinct TPMS that accurately reflect key parameters or risk factors, are readily measurable, and that can be affected by altering design decisions will make the most effective use of resources. Some TPMs may apply to the entire program/project, such as mass and power margins; some parameters may apply only to certain systems or subsystems. The overall set of TPMs that the program/project will be tracking should be documented in the Formulation Agreement and Program/Project Plan.

3.7.2. Mass Margin and Power Margin

These two indicators are required per NPR 7123.1. For most programs/projects that produce a product that is intended to fly into space, mass and power consumption are critical parameters and are therefore considered a common Technical Leading Indicator. Programs/projects may choose to track raw mass and power, but perhaps a more informative indication is that of mass or power margins. As the concepts are fleshed out, a determination of how much a given launch vehicle can provide lift to the desired orbit/destination will be determined. This in turn will place limits on the products that the program/projects may be providing. Availability of solar, nuclear, battery, or other power sources will also place a limit on how much power the various systems may consume. These parameters will be flowed down and allocated to the subsequent systems, subsystems, and components within the program/project's product. Tracking the ability of the overall product and its lower level components to accomplish their mass and power goals becomes critical to ensure the success of the program/project. How far down into the product hierarchy that the program/project decides to track these parameters is left up to the program/project.

Table 3-12 is an example of a spreadsheet that tracks the mass margin of a product. The margins are estimated prior to the actual manufacturing of the product and measured after it is produced. When reporting at the overall program/project level, the parameter may be a combination of estimates for subsystems/components that have not yet been produced and measured mass of those that have been produced. A similar spreadsheet can be developed for power margins.

Table 3-12 Example Spreadsheet for Tracking Mass Margin

Date	Mass Margin	Planned Margin	Upper Tol	Lower Tol	Req.	Goal
1/1/11	1	15	20	10	0	4
2/1/11	-2	14	19	10	0	4
3/1/11	-3	13	18	9	0	4
4/1/11	9	12	17	8	0	4
5/1/11	9	11	15	8	0	4
6/1/11	8	10	15	7	0	4
7/1/11	8	9	13	7	0	4
8/1/11	8	8	11	6	0	4
9/1/11	6	7	10	6	0	4
10/1/11	3	7	8	5	0	4
11/1/11	1	6	8	5	0	4
12/1/11	-2	6	7	5	0	4
1/1/2012	-3	5	7	4	0	4
2/1/2012	-2	5	6	4	0	4
3/1/2012	-1	4	5	4	0	4
4/1/2012	-1	4	4	4	0	4

Perhaps a more effective way of displaying power or mass margin TPMs is graphically. Figure 3-16 is an example of displaying the mass margins for a particular program/project. A similar plot can be developed for power margin TPM.

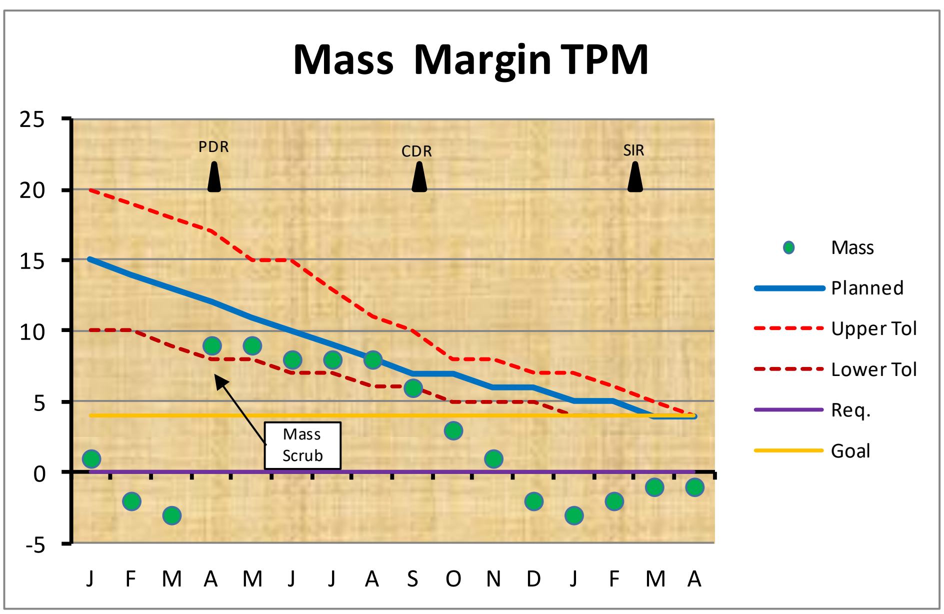


Figure 3-16 Example Plot for Mass Margin Indicator

3.7.3. Project-Unique TPMs

In addition to Common Leading Indicators, a program/project may need to identify other TPMs that are unique to the particular type of program/project that is being conducted. For example, if the project is avionics based, additional performance parameters such as bandwidth, pointing accuracy, and memory usage may be important to track in order to ensure that the project is meeting its design requirements. However, if the project is more mechanically based, these parameters may not be important/applicable, but others such as stress, envelope size, or actuator force may be. There are many parameters that a project can and will measure at some level. TPMs should be that selected subset that most affect the design or performance of the program/project and should be tied to the Measures of Effectiveness and Measures of Performance as described in NPR 7123.1 and NASA/SP-2007-6105, *NASA Systems Engineering Handbook*.

Table 3-13 is an example of some other TPMs that the program/project may consider. The specific project unique TPMs that the program/project decides to use should be documented in the Formulation Agreement and the Program/Project Plan and/or the Systems Engineering Management Plan.

Table 3-13 Example Project-Unique TPMs

Example Project-Unique TPMs		
Pointing error	Database Size	RF Link Margin
Data Storage	Lines of code	Torque Factor
Throughput	Thrust	Strength Factor
Memory available	Time to restore	Cooling capacity
Speed	Fault Tolerance	Range
Reliability	Utilization	MTBF
Human Factors	Pointing Accuracy	Specific Impulse
Response time	Jitter	Other Margins
Availability	Propellant	Control stability

3.8. Manufacturing Trends

Manufacturing trends are intended to provide quantifiable evidence of potential technical problems, monitor performance, and reveal the most important problems that affect a system that could substantially affect cost, schedule, and quality and threaten a project’s success. During manufacturing, nonconformances are typically documented and resolved using a Materials Review Board (MRB) process, or its equivalent. Once non-conforming material or parts (items that fail inspection, i.e., are rejected) have been identified, the MRB reviews them and determines whether the material or parts should be returned, reworked/repaired, used “as is,” or scrapped. The MRB also identifies potential corrective actions for implementation that would prevent future discrepancies.

3.8.1. Why is the Leading Indicator Important?

Leading indicators are important so the manufacturing discipline can conduct analysis and trending on component and system requirements, materials, controlled/critical processes, and production problems. At the manufacturing stage of the life cycle, problems can quickly become critical path schedule drivers with accompanying adverse cost impacts. Early warning indicators are needed to provide triggers for project risk mitigation decisions. For example, a pattern of frequent inspection failures of a particular vendor's printed circuit boards might indicate a need to investigate and correct root cause(s) or change vendors. A trend showing a high number of scrapped weldments might be the result of an inadequate weld schedule. Such problems can slow down or even bring production work to a halt. Finding and qualifying a new printed circuit board vendor or going back into research and development to tighten up a weld schedule could impose serious cost and schedule penalties.

3.8.2. Number of MRB Non-conformance/Corrective Actions

The program/project should establish a measure of nonconformances as a function of time. Figure 3-17 shows an example of how this can be depicted. In this case, "units" could refer to piece parts of an assembly or subassembly item.

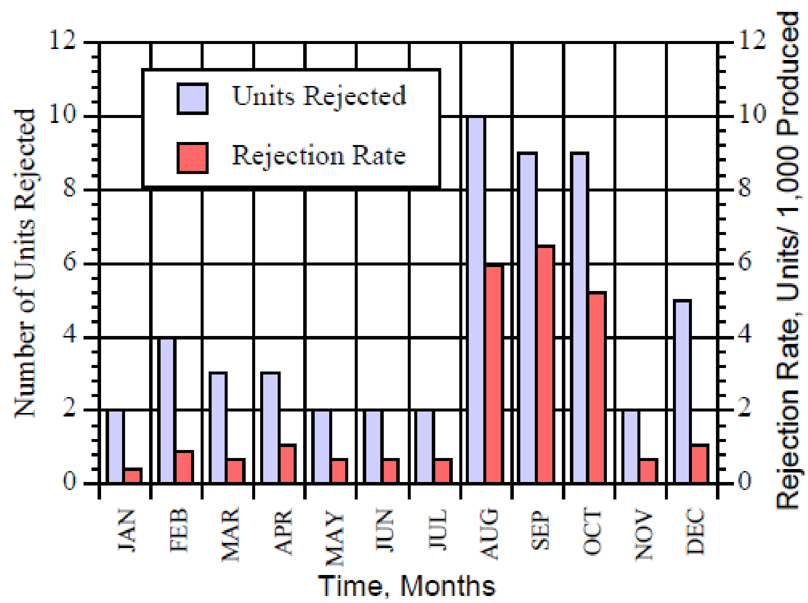


Figure 3-17 Parts Rejection Rate over Time

Programs/projects should compare such information against production schedules. For example, the number of rejected units should be assessed against both the actual and planned number of items in manufacturing using the same time scale as the nonconformance metric. Trends in performance can be identified by observing the percentages of non-conformances over time, looking for increases or decreases.

The number of corrective actions initiated and implemented over time will provide an indication of the health of the corrective action system. Measuring the initiation of corrective actions shows the quality system's sensitivity to deficiencies. Measuring implemented corrective actions and comparing them with trends in non-conformances post-implementation would be an indicator of the effectiveness of the overall manufacturing, quality control, and supply chain systems and risks.

4.0 Programmatic Leading Indicators

Like Technical Leading Indicators, Programmatic Leading Indicators are intended to provide program and project personnel and Agency leaders with insight into cost, schedule, and staffing performance trends. Sustained underperformance in these areas can result in project or program failure to meet internal or external programmatic commitments. The indicators recommended here are intended to supplement other reporting conventions and requirements that may be specified by other functional or programmatic authorities.

4.1. Cost Trends

This category is intended to provide a longer temporal perspective than is sometimes provided in reporting required by the owner of the cost function.

4.1.1. Why is the Leading Indicator Important?

Living within the internal and external cost commitments is becoming increasingly important. Stakeholders are requiring more stringent cost and schedule control for projects. Since cost and schedule are so tightly correlated, schedule growth frequently translates into cost growth. The earlier that cost and schedule issues can be identified and addressed, the less the impact to total cost. With more effective cost and schedule management, NASA can maximize the return on its investment of taxpayer resources.

4.1.2. Plan vs. Actual

Tracking the performance of actuals against the plan enables recognition of the potential impacts of delayed receipt of funds and the effects of spending above or below the plan. Since most Centers, programs, and project organizations will have preferred formats for tracking the cost and obligations performance for the current year (year of execution), the leading indicator here proposes to track the quarterly performance in obligations against multi-year plans for New Obligations Authority in both the Agency Baseline Commitment (ABC) and the project Management Agreement as well as a multi-year cost plan for the project. Analyzing current project Estimate at Completion (EAC) and life-cycle cost plans will enable more immediate identification of potential issues that could affect the overall ABC. By monitoring the extent to which either the Agency or project is unable to realize the basis for their commitments, management will be encouraged to consider whether an adjustment in the agreements and recalculation of confidence levels should be pursued.

The addition of quarterly reporting of actual costs against a multi-year cost plan will enable management to regularly monitor any trends of ongoing expenditures, either in excess or below the plans that are tied to the internal and external cost and schedule commitments. This perspective is often not regularly reported in monthly project status reports.

As with the other leading indicators, the data may be displayed in either tabular or graphical form. Examples are shown below.

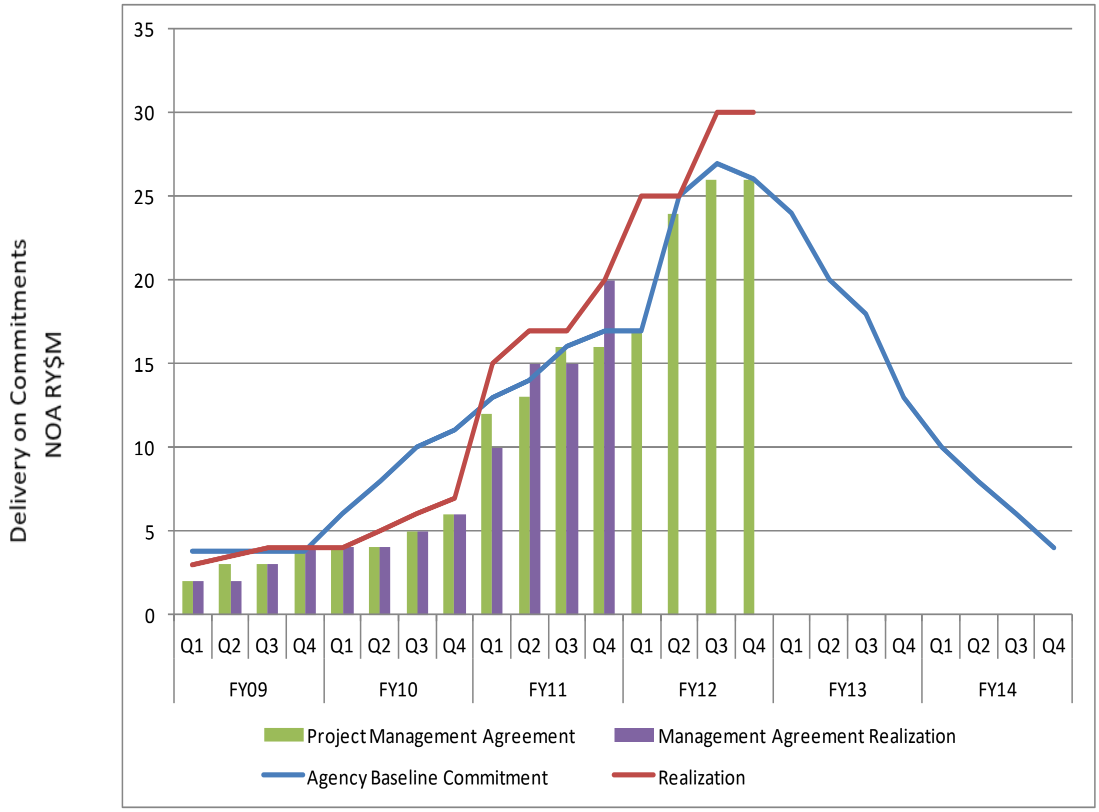


Figure 4-1 Management Agreement and ABC Plan vs. Actual

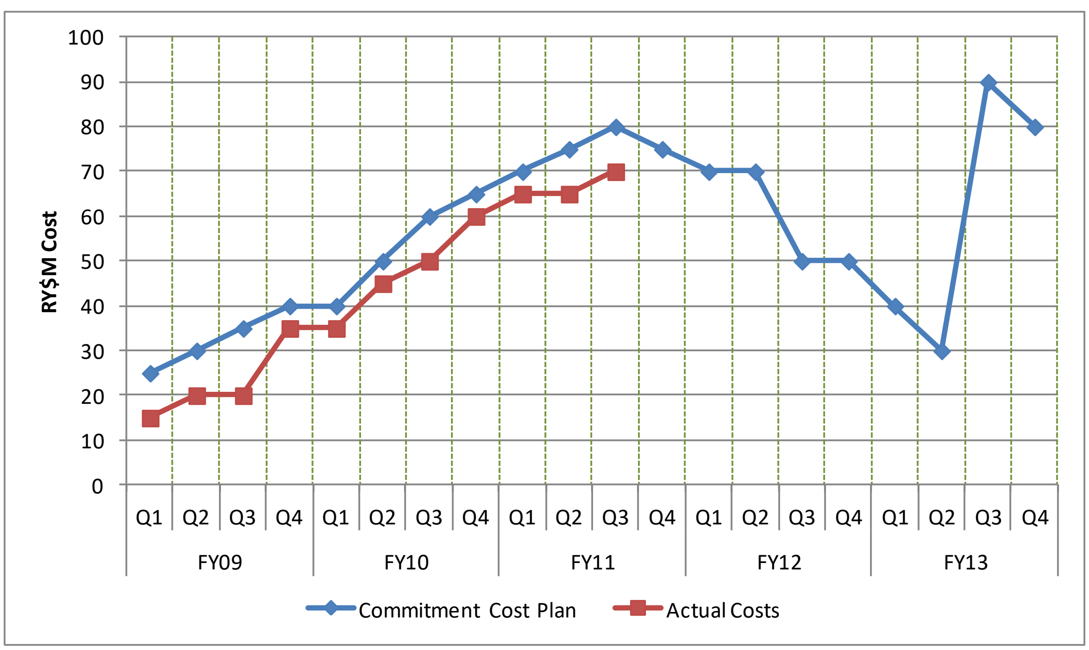


Figure 4-2 Commitment Cost Plan vs. Actual

Table 4-1 Spreadsheet Example for Capturing Plan vs. Actual Measures

Date	ABC NOA		Mgmt Agreement		Cost	
	Plan	Actual	Plan	Actual	Plan	Actual
FY16Q1	$100	$10	$80	$8	$20	$5
FY16Q2	$100	$40	$80	$35	$40	$30
FY16Q3	$100	$60	$80	$55	$60	$50
FY16Q4	$100	$100	$80	$80	$80	$65
FY17Q1	$200	$30	$170	$25	$30	$15
FY17Q2	$200	$60	$170	$55	$60	$40
FY17Q3	$200	$120	$170	$110	$130	$90
FY17Q4	$200	$200	$170	$170	$170	$150
FY18Q1	$300	$100	$270	$90	$50	$45
FY18Q2	$300	$300	$270	$200	$120	$115
FY18Q3	$300	$300	$270	$270	$220	$250
FY18Q4	$300	$300	$270	$270	$270	$275
FY19Q1	$200	$50	$180	$45	$40	$35
FY19Q2	$200	$100	$180	$90	$80	$75
FY19Q3	$200	$150	$180	$140	$150	$130
FY19Q4	$200	$180	$180	$180	$180	$180

Note: $M. Amounts are cumulative per year

4.1.3. UFE

Measuring the use of cost margins—Unallocated Future Expenses (UFE)—against a plan enables evaluation of time-phased releases in the context of the planned life-cycle activities and identified risks. Utilization of UFE ahead of the anticipated needs and phasing may signal threats to the life-cycle cost estimates or schedules, as it may indicate that identified risk mitigation needs have been underscoped, that unidentified risks are being realized, that scope has been added, or baseline costs underestimated. UFE plans and actuals should be measured for both project-managed and Agency-managed UFE.

Multi-year plans should incorporate local guidance or rules of thumb, and reporting should note reasons for major releases or expenditures. Reporting may be done in either tabular or graphical form, as illustrated in the examples below.

Table 4-2 Example Spreadsheet for Project and Agency UFE Usage

Date	PM UFE Plan	Agency UFE Plan	PM UFE ($M)	Agency UFE ($M)
FY16Q1	70	20	$70	$20
FY16Q2	70	20	$70	$20
FY16Q3	70	20	$70	$20
FY16Q4	70	20	$70	$20
FY17Q1	70	20	$65	$20
FY17Q2	70	20	$65	$20
FY17Q3	70	20	$60	$20
FY17Q4	60	20	$55	$20
FY18Q1	60	20	$40	$15
FY18Q2	60	20	$40	$15
FY18Q3	60	20	$40	$15
FY18Q4	50	20	$30	$15
FY19Q1	50	20	$30	$15
FY19Q2	50	20	$20	$15
FY19Q3	40	20	$20	$10
FY19Q4	40	20	$10	$10

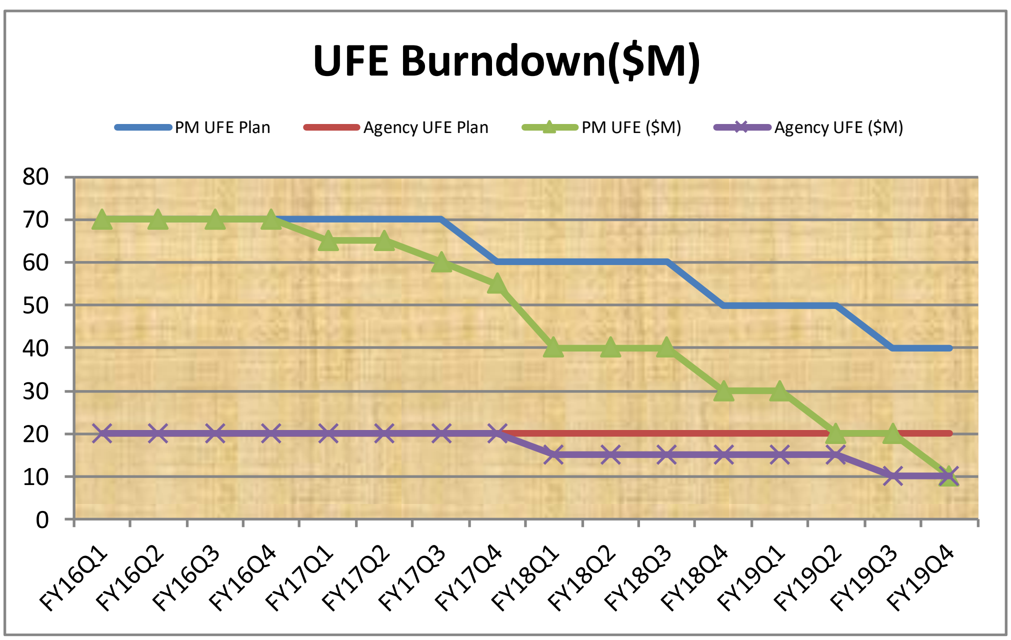


Figure 4-3 UFE Burndown with Life-Cycle Review Notations

4.1.4. EVM

Earned Value Management (EVM) is one of the recognized methods of measuring integrated cost and schedule performance against a plan. Based on the recorded performance to date, EVM will identify variances, help identify trends, and predict resulting changes in the schedule and Estimate at Completion (EAC). Traditionally reserved for application on contracts, NASA has extended EVM application to the project level, taking in the integrated performance on multiple contracts and civil service efforts.

EVM establishes a baseline for measuring progress. That is, accomplishment (also known as Budgeted Cost of Work Performed (BCWP) is compared to the Actual Cost of Work Performed (ACWP) to determine cost variances and compared to the Budgeted Cost of Work Scheduled (BWCS) to identify schedule variances. Additionally, the Cost Performance Index (CPI) and Schedule Performance Index (SPI) can be generated from the Earned Value Measurement System. As shown in Figure 4-5, A CPI >1 indicates the project is under-running costs, whereas a CPI<1 indicates an over-run. Likewise, a SPI >1 indicates the project is ahead of schedule and an SPI <1 indicates being behind schedule. The EVMS provides trend analyses and can generate a mathematical EAC, which can be compared to the Budgeted Estimate at Completion (BAC). Several software packages (e.g., wInsight) will generate a series of mathematical EACs that can provide the project with an estimated range of EAC possibilities based on trend information.

The graph below illustrates a trend analysis of the EAC, CPI, SPI, and the available/planned BAC. Although the display below is an example of a contractor report and limited to a one-year period, the reported elements are those intended for application at the project level. Reporting across multiple years is expected. Early in the project, level of effort tasks can dominate and effectively cancel out useful reporting on other elements, so if it is possible it is most desirable to report the results both with and without the Level of Effort (LOE) elements.

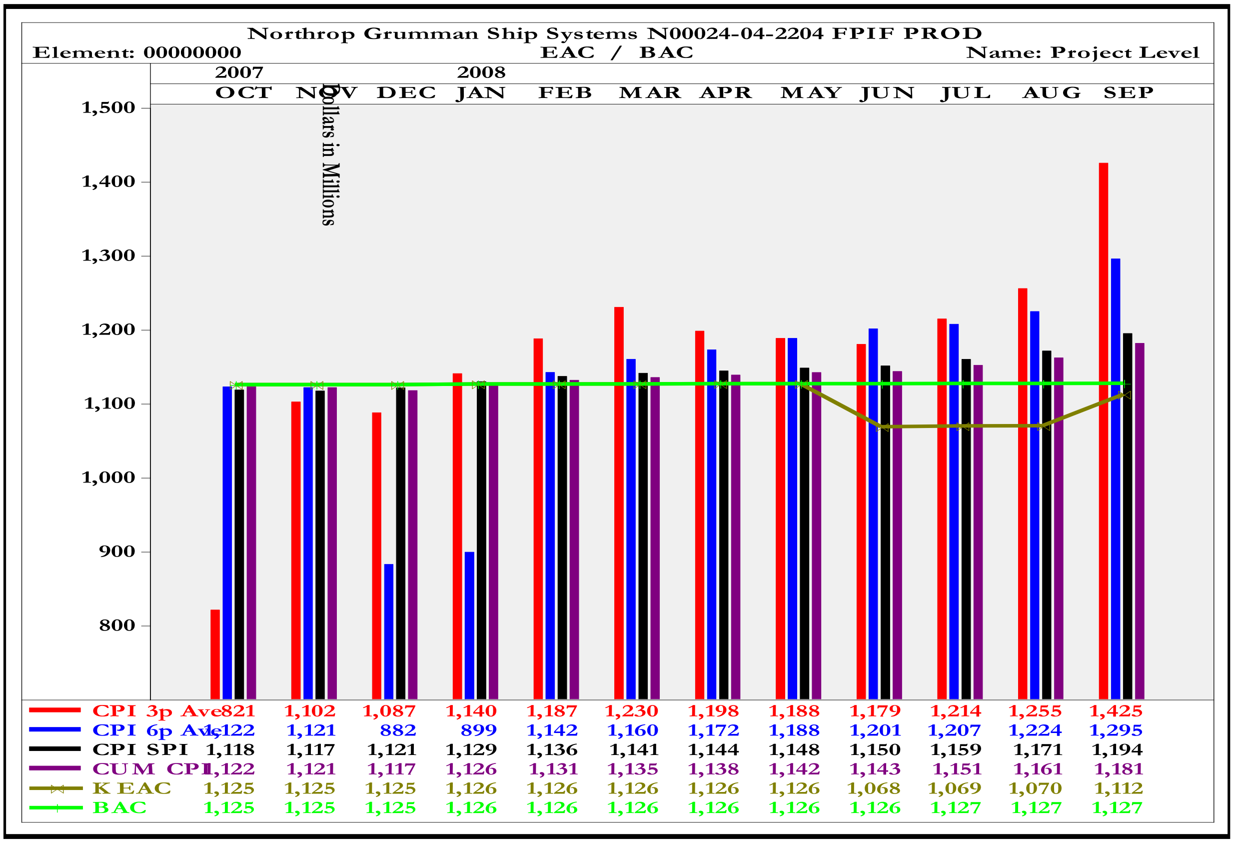


Figure 4-4 Example Plot of EVM Parameters

The display below provides more insight into the variation of the CPI and SPI over time and the "bullseye" provides at a glance interpretation of the performance.

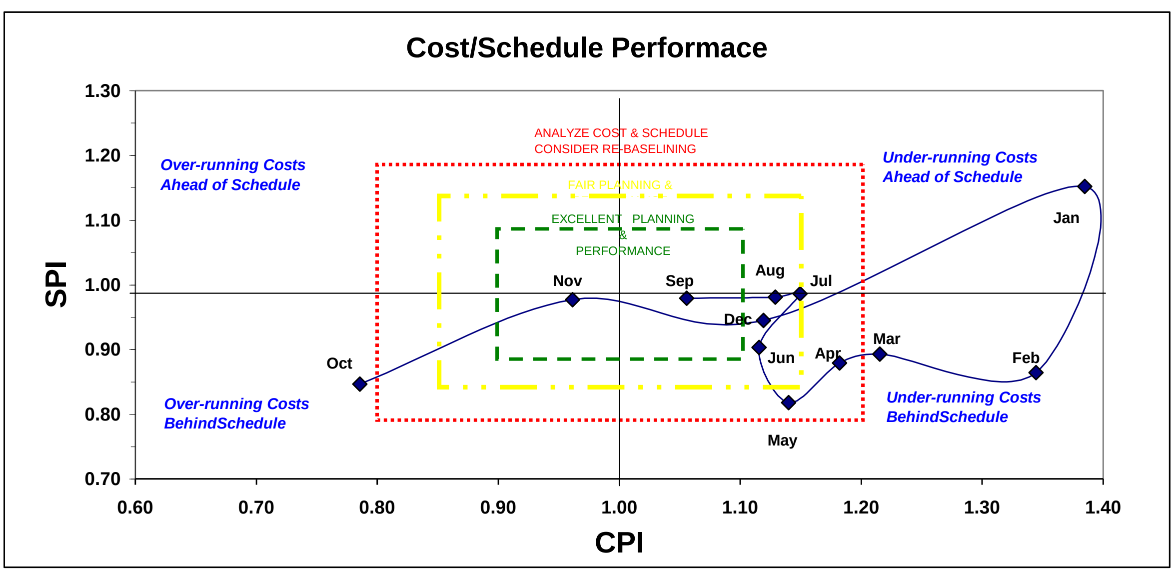


Figure 4-5 EVM CPI vs. SPI Bullseye Chart Example

Earned Value reporting is most useful when the project baselines are stable. If there is a substantial amount of flux in the baselines (either cost or schedule), the project earned value baseline may rapidly become out of date and the reporting against an out of date baseline may be less than helpful. In those instances, the project should provide alternative means of measuring integrated cost and schedule performance.

4.2. Schedule Trends

4.2.1. Why is the Leading Indicator Important?

Tracking schedule trends over a multi-year horizon provides an easily interpreted means of measuring progress. Because of the strong correlation between cost and schedule, schedule performance is a good predictor of cost performance. Although current reporting practices provide current schedules, tracking near term milestones within the current year, and a status on the use of schedule margins, the shortened performance period does not provide a complete picture of total performance.

4.2.2. Critical path slack/float

The best reporting practices on the status of schedule margin and slack provide data against an anticipated burndown or plan, along with acceptable ranges and explanations of major releases/uses of margin or slack. Premature use of slack in the early phases of the life cycle may indicate the inability to deliver products as planned. The first example below shows the actual performance against plan, identifies the critical ranges of remaining slack, and provides primary reasons for the release or use of slack within a single year.

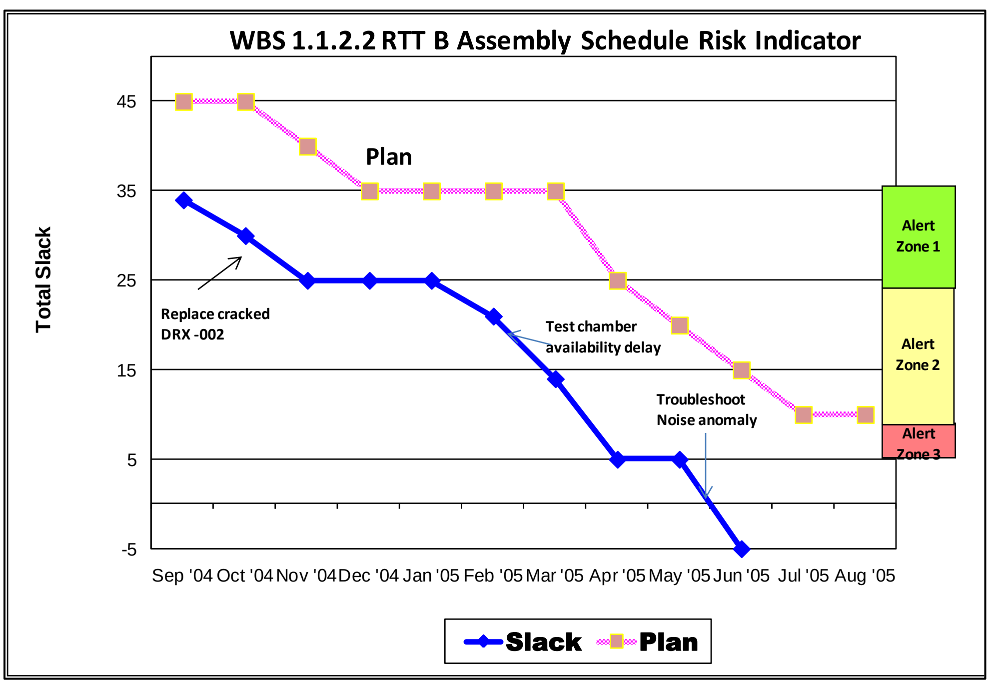


Figure 4-6 Example of Project Schedule Slack vs. Plan

Ideally, the display would report against multiple years on the same trend lines as the tabular example below.

Table 4-3 Spreadsheet Example for Capturing Schedule Slack

Date	Total Sched Slack (Months)	Planned Milestones	Completed Milestones	% Completed Milestones
FY16Q1	20	0	0	0%
FY16Q2	20	1	0	0%
FY16Q3	15	3	1	5%
FY16Q4	15	4	3	15%
FY17Q1	15	5	5	25%
FY17Q2	12	6	5	25%
FY17Q3	12	8	5	25%
FY17Q4	12	9	6	30%
FY18Q1	9	10	6	30%
FY18Q2	9	11	7	35%
FY18Q3	9	12	8	40%
FY18Q4	4	13	9	45%
FY19Q1	4	14	11	55%
FY19Q2	2	15	12	60%
FY19Q3	2	16	13	65%

4.2.3. Critical Milestone Dates

It is equally important that the project provide a multi-year trend analysis of its overall schedule achievement. The project should identify a limited number of significant predictive milestones and track their achievement. The selection focuses on events that are key to delivering readiness for the life-cycle phase or achieving the mitigation of a significant risk. That is, projects must go beyond major milestone events and focus on the larger series of intermediate milestones and activities to understand progress against the plan. These milestones typically would relate to drivers of risk or cost. The display should show plan vs. actual achievements in a cumulative fashion over the planned development period. A quarterly display is generally sufficient to provide a useful trend, as illustrated below.

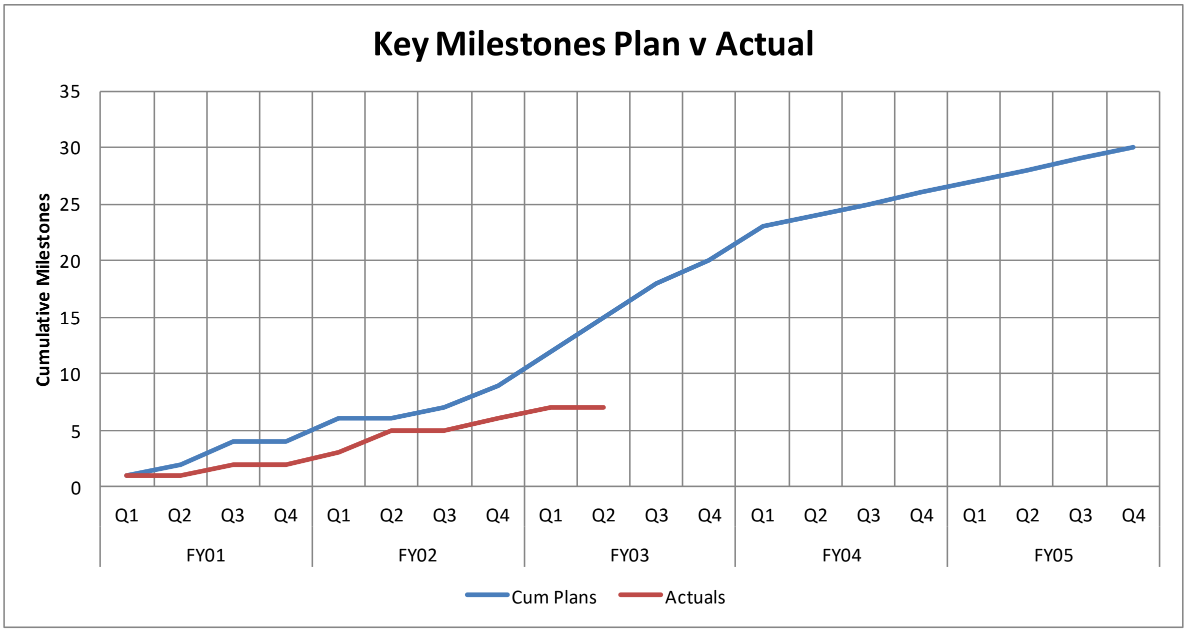


Figure 4-7 Cumulative Number of Milestones Planned in a Time Period vs. the Number Actually Accomplished.

4.3. Staffing Trends

4.3.1. Why is the Leading Indicator Important?

The inability to properly staff positions may indicate an increased risk of not meeting cost and schedule plans and could indicate product quality issues. Staffing trends should be reported for Civil Servant FTE and Support Service Contractor WYE, as well as Prime Contractor WYE. It is important to monitor all three staffing trends since it is sometimes possible to reassign work among available resources, e.g. Prime Contractor to In-house. Current reporting practices are frequently limited to the execution year, but it is most helpful to take a longer trend view of staffing.

In addition, since the majority of the cost associated with the development of hardware or software is the cost of personnel, it is critical that staffing plans be monitored as a key indicator of whether the project is heading in a direction that is likely to lead to a cost overrun. It is frequently useful to look at both labor costs and FTE or WYE.

4.3.2. FTE/WYE Planned vs. Actual

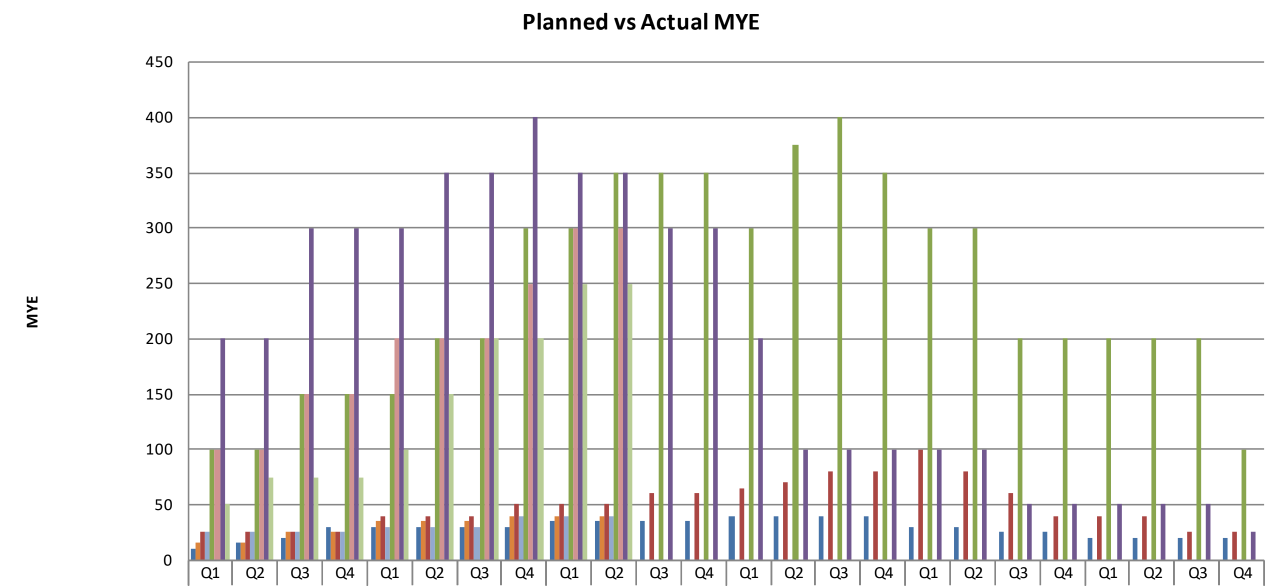
Reporting staffing level plan vs. actuals can be handled in either tabular or graphical format. It may be useful to provide a longer-term trend on a quarterly basis as a supplement to the reporting being done for the year of execution. A tabular display example is provided in Table 4-4.

Table 4-4 FTE and WYE Staffing Levels Planned vs. Actual

Date	FTE		WYE $	
	Planned	Actual	Planned	Actual
FY16Q1	12.2	10.5	$450	$400
FY16Q2	12.5	11.5	$470	$450
FY16Q3	13.1	12.8	$470	$450
FY16Q4	13.1	12.9	$470	$470
FY17Q1	11.5	12.1	$480	$400
FY17Q2	12.3	12.3	$540	$480
FY17Q3	13.5	13.1	$540	$490
FY17Q4	13.5	13.2	$500	$520
FY18Q1	10.5	9.1	$400	$350
FY18Q2	11.2	10.5	$450	$420
FY18Q3	12.5	12.8	$450	$460
FY18Q4	12.6	12.8	$400	$410
FY19Q1	8.8	9.1	$300	$280
FY19Q2	9.5	9.2	$350	$330
FY19Q3	9.1	8.8	$300	$320
FY19Q4	8.5	8.6	$250	$260

4.3.3. Fully Integrated Staff Year Equivalent reporting

As noted, a fully integrated view can be useful in understanding why costs may be running either below or ahead of plan and it can quickly identify questions that should be posed about the reassignment of work and the related cost and schedule consequences. In the illustration below, it is apparent that the instrument developers are running well behind plan, which should raise questions about the viability of the planned schedule.



	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	FY09				FY10				FY11				FY12				FY13				FY14			
Plan CS	10	15	20	30	30	30	30	30	35	35	35	35	40	40	40	40	30	30	25	25	20	20	20	20
ACT CS	15	15	25	25	35	35	35	40	40	40														
Plan SSC	25	25	25	25	40	40	40	50	50	50	60	60	65	70	80	80	100	80	60	40	40	40	25	25
ACT SSC	25	25	25	25	30	30	30	40	40	40														
Plan Prime	100	100	150	150	150	200	200	300	300	350	350	350	300	375	400	350	300	300	200	200	200	200	200	100
ACT PRIME	100	100	150	150	200	200	200	250	300	300														
Plan Instr vendors	200	200	300	300	300	350	350	400	350	350	300	300	200	100	100	100	100	100	50	50	50	50	50	25
ACT INSTR VENDOR	50	75	75	75	100	150	200	200	250	250														

Figure 4-8 Example of Fully Integrated Staff Reporting

5.0 References

1. NASA/SP-2016-6105 “NASA Systems Engineering Handbook,” Rev 2 , 2016
2. “Systems Engineering Leading Indicators for Assessing Program and Technical Effectiveness,” Donna H. Rhodes, Ricardo Valerdi, Garry J. Roedler. Massachusetts Institute of Technology and Lockheed Martin Corporation. Reprint of an article accepted for publication in Systems Engineering, 2008
3. “Systems Engineering Leading Indicators Guide,” Version 2.0, MIT, INCOSE and PSM joint paper, 2010
4. “Metric Guidebook for Integrated Systems and Product Development,” INCOSE, 1995
5. “Technical Measurement,” a Collaborative Project of PSM, INCOSE and Industry, 2005
6. BAE Presentation “Technical Performance Measure,” Jim Oakes, Rick Botta, and Terry Bahill, 2005

Appendix A Acronyms

ABC	Agency Baseline Commitment
ACWP	Actual Cost of Work Performed
BAC	Budgeted Estimate at Completion
BCWP	Budgeted Cost of Work Performed
CDR	Critical Design Review
CPI	Cost Performance Index
DR	Discrepancy Report
EAC	Estimate at Completion
EVM	Earned Value Management
FTE	Full-time Equivalent
ICD	Interface Control Document
INCOSE	International Council on System Engineering
MRB	Material Review Board
NASA	National Aeronautics and Space Administration
NOA	New Obligation Authority
PDR	Preliminary Design Review
PLI	Programmatic Leading Indicator
PM	Program or Project Management
PR	Problem Report
PSM	Practical Software and Systems Measurement
RFA	Request For Action
RID	Review Item Discrepancy
SAR	System Acceptance Review
SDR	System Definition Review
SEMP	Systems Engineering Management Plan
SIR	System Integration Review
SPI	Schedule Performance Index
SRB	Standing Review Board
SRR	Systems Requirement Review
TBD	To Be Determined
TBR	To Be Resolved
TLI	Technical Leading Indicator
TPM	Technical Performance Measure
UFE	Unallocated Future Expenditures
WYE	Work Year Equivalent

Appendix B Glossary

Deviation: a documented agreement intentionally releasing a program/project from meeting a requirement prior to the Implementation phases of the life cycle.

Leading Indicator: a measure for evaluating the effectiveness of how a specific activity is applied on a program in a manner that provides information about impacts likely to affect the system performance objectives. A leading indicator may be an individual measure or collection of measures predictive of future system [and project] performance before the performance is realized. The goal of the indicators is to provide insight into potential future states to allow management to act before problems are realized.

Technical Performance Measure: a critical or key performance parameter that is monitored by comparing the current actual achievement of the parameter with that anticipated at the current time and on future dates.

Verification: the proof of compliance with program/project requirements. This can be done through test, analysis, demonstration, or inspection. Each requirement will need to be verified through one or more of these methods.

Waiver: a documented agreement intentionally releasing a program/project from meeting a requirement after reaching the Implementation phases of the life cycle.

Appendix C Summary of Common Indicators

Type	Indicator	Calculation	• Min. Graph Characteristics
Requirements Trend	Requirement Growth	• Number of Requirements per document and/or in total • Percent growth (((Current number req) – (previous number req))/(previous number req)) x 100	• Show volatility of requirements over time: Requirement growth vs. time or # req vs. time • Indicate key milestones for reference • Include descriptions of key events
Requirements Trend	TBD/TBR Burndown	• Number of TBD/TBRs per document and/or in total	• Show how TBD/TBRs are being resolved over time: TBD/TBR burndown vs. time or % closure vs. plan vs. time • Indicate key milestones for reference • Include descriptions of key events
Requirements Trend	Pending Req. Changes	• Number of pending requirement change requests per document and/or in total	• Show pending requests for requirement changes over time • Indicate key milestones for reference • Include descriptions of key events
Interface Trend	Interface Documentation approved/pending	• Number of Interface documents approved/Total number of interface documents x 100	• Show volatility of interfaces over time: Interface growth vs. time or # interfaces vs. time • Indicate key milestones for reference • Include descriptions of key events
Interface Trend	TBD/TBR Burndown	• Number of TBD/TBRs per document and/or in total	• Show how TBD/TBRs are being resolved over time: TBD/TBR burndown vs. time or % closure vs. plan vs. time • Indicate key milestones for reference • Include descriptions of key events
Interface Trend	Pending Req. Changes	• Number of pending requirement change requests per document and/or in total	• Show pending requests for interface changes over time • Indicate key milestones for reference • Include descriptions of key events

Type	Indicator	Calculation	• Min. Graph Characteristics
Verification Trend	Verification Burndown	• Number of open verifications/Total number of verifications x 100	• Show how verifications are being resolved over time: open verification burndown vs. time vs. plan or % closure vs. plan vs. time • Indicate key milestones for reference • Include descriptions of key events
	Number of deviations/waivers	• Number of approved and pending deviations/waivers	• Show approved and pending requests for deviations/waivers over time as a number or percentage • Indicate key milestones for reference • Include descriptions of key events
Review Trend	Open RFAs/RIDs/AIs per Review	• Number of open comments/Total number of comments x 100	• Show number of open review RFAs/RIDs/AIs over time as a number or percentage • Indicate key milestones for reference • Include descriptions of key events
Software-unique Trend	Number of requirements per build/release vs. plan	• Number of software requirements for each build or release	• Show number of requirements accomplished for each build vs. planned • Indicate key milestones for reference • Include descriptions of key events
Problem Report/Discrepancy Report Trend	Open PR/DRs	• (Number of open PR/DRs/Total number PR/DRs) x 100	• Show number of open PR/DRs over time as a number or percentage • Indicate key milestones for reference • Include descriptions of key events

Technical Performance Measures	Mass Margin	• Measured/calculated mass margin	• Show how mass margins are being used over time: margin vs. time vs. plan or raw mass value vs. plan vs. time with limits indicated • Indicate key milestones for reference • Include descriptions of key events
	Power Margin	• Measure/calculated power margin	• Show how power margins are being used over time: margin vs. time vs. plan or raw power value vs. plan vs. time with limits indicated • Indicate key milestones for reference • Include descriptions of key events
	Project-unique	• Trending of other TPMs selected by project	• Show trending of the project unique TPMs over time • Indicate key milestones for reference • Include descriptions of key events
Cost Margin Trend	Expenditure of UFE	• UFE Release plan vs. actual	• Show multi-year plans for use of UFE • Incorporate local guidance/rules of thumb • Track actual against plans • Include description of major releases
Schedule Margin Trend	Total slack time	• Schedule slack in appropriate units (days, months)	• Track margin against plan • Explain major releases/use • Can include performance against rules/exceptions

Cost Trend	PM Agreement NOA	• Project Management Agreement NOA received	• Current Agreement vs. planned • Detail by quarter for multiple years • Indicate key milestones for reference • Include descriptions of key events
	Cost	• Actual costs incurred by program/project	• Plan vs. Actual costs • Detail by quarter for multiple years • Indicate key milestones for reference • Include descriptions of key events
	EVM	• BCWS – Budgeted Cost of Work Scheduled (AKA "Plan") • ACWP – Actual Cost of Work Performed (AKA "Actuals) • BCWP – Budgeted Cost of Work Performed (AKA "Earned Value) • CPI = BCWP/ACWP (If < 1, over-running costs; if > 1, under-running costs) • SPI = BCWP/BCWS (If <1, behind schedule; if >1, ahead of schedule) • EAC = Estimate at Completion of Project	• Include CPI, SPI and EAC • Minimum of one-year, multiple years preferred • If possible, report without LOE elements as well as total • Include additional evaluations of performance, e.g. non EVMS where possible • Indicate key milestones for reference • Include descriptions of key events
Staffing Trend	FTE	• Civil servant charges to program/project	• Plot as FTE number and/or in equivalent dollars • Show as multi-year trend of plan vs. actuals • Indicate key milestones for reference • Include descriptions of key events
	WYE	• Contractor support–primes, subcontractors, support contractors	• Plot as dollar equivalents • Show as multi-year trend of plan vs. actuals • Indicate key milestones for reference • Include descriptions of key events

Appendix D Additional Indicators to Consider

In addition to the common leading indicators described in this guide, many other indicators or measurements can be selected for a program/project. Some examples are provided below:

- Requirements Trends
    - Percent requirements approved
    - Estimated impact of requirement changes
    - Requirement defect profile
    - Requirement defect density
    - Requirement defect escapes
    - Cycle time for requirement changes
    - Requirement validation rate
    - Percent requirements validated
    - Number of requirements
    - Requirement completion status
    - Number of waivers/deviations
    - Number of change request and closure status
    - Requirement traceability
- Verification trends
    - Verification rate
    - Percent requirements verified
    - Past due verifications
    - Actual vs. planned closures
    - Requirement verification by event
    - Requirement liens
    - Number of approved waivers
    - Number of open waivers
    - Potential waivers
    - Waiver risk level
- Work product approval
    - Work product approval rate
    - Distribution of dispositions for work products
- Staffing trends
    - Organizational turnover
    - Costing profile
    - Key staffing positions that need to be filled
    - Performance variance at subsystem level
    - Staffing in relation to SPI trends
    - Workforce composition diversity

- Risk
  - Risk exposure
  - Present risk mitigations closed
  - Percent risk mitigations overdue
- System design trends
  - Interface trends
    - Percent interface growth
    - Interface defect profile
    - Interface defect density
    - Interface defect escapes
    - Cycle time for interface changes
    - Rate of convergence of interfaces
    - Total number of interface requirements
    - ICD changes
    - Delays in baseline ICD
  - Change request approval/closure rates
  - Change request cycle time
  - Change request priority density
  - Complexity index
  - Technology maturity
    - Monitoring of breadboard, engineering models, simulations
    - Technology opportunity exposure
    - Technology obsolescence
    - TRL level maturity per plan
  - Use of heritage systems
  - Risk exposure trend
  - Drawing/model maturity
- Process compliance
  - Percent processes with discrepancies
  - High risk processes
- Software Trends
  - Change requests
  - Facility development (testbeds)
  - Software code Peer Review comment count
  - SW milestone status
  - SW plan vs. release
  - SW module planned vs. actual completions
  - Margin management on constrained resources
  - Requirements allocation to software components & builds
  - Software size in terms of Source Lines of Code or function points
  - Software development effort in terms of staff hours or staff months

    - Software development staffing in terms of actual staffing vs. planned staffing and staff turnover
    - Software development schedule start and completion dates
    - Progress for detailed activities tracked against baseline plans
    - Software defects
    - Defect resolution effort in staff hours or staff months
    - Defect resolution schedule start and completion dates
    - Progress for defect resolution tracked against baseline plans
- Manufacturing trends
    - Released for manufacturing
    - Number of nonconformances that are opened, closed, resolved
    - Number of open/closed inspection reports vs. time
- Facility and equipment availability
    - Facility availability
    - Equipment availability
- Review trends
    - Action item closure performance
    - Closure disposition distribution
    - Number of document comments
    - RFA status (open, closed, overdue)
- Cost/Schedule Trends
    - Affordability
    - Cost/schedule pressure
    - Joint Confidence Level
    - Replans
    - Variance explanations
    - Past performance UFE vs. Center guidelines
    - Liens
    - Threats
    - Estimate at completion
    - Time between schedule milestones
    - Late task finishes
    - Received/delivered products actual vs. plan
    - SRA
    - Cost of missions in extended operations
    - Cost increase due to external forces (Continuing resolutions, new requirements, etc.)
    - International partnership performance
- Other
    - EEE parts approval
    - Parts procurement and delivery trend
    - Reliability analysis actual vs. planned completions

- Open design analysis discrepancy completion
- Completion of certification of flight readiness (CoFR) items vs. plan
- Number of drawing planned vs. actual over time
- Hardware build statue
- Problems, issues, and concerns over time
- Contract value
- Contract mods metrics
- Supplier and supply chain management
- Production metrics
- Contractor/subcontractor performance ratings
- Key programmatic and technical risk
- TRL levels planned vs. actual
- Risk status/mitigation implementation