Building a Credible Performance Measurement Baseline[†]

Establishing a credible Performance Measurement Baseline, with a risk adjusted Integrated Master Plan and Integrated Master Schedule, starts with the WBS and connects Technical Measures of progress to Earned Value

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INTRODUCTION

EIA-748-C asks us to "objectively assess accomplishments at the work performance level." As well §3.8 of 748-C tells us "Earned Value is a direct measurement of the ***quantity*** of work accomplished. The ***quality*** and ***technical content*** of work performed is controlled by other processes." [6]

Without connecting the technical and quality measures to Earned Value, CPI and SPI provide little in the way of assuring the delivered products will actually perform as needed. To provide visibility to integrated cost, schedule, and technical performance, we need more than CPI and SPI. We need measures of the increasing technical maturity of the project's system elements in units of measure meaningful to the decision makers. Those units include Effectiveness, Performance, all the *…"ilities"*, and risk reduction.[‡]

PROCESSES TO INCREASE THE PROBABILITY OF PROGRAM SUCCESS

With the management processes in **Table 1**, the elements in **Figure 1** are the basis of a credible Performance Measurement Baseline (PMB) needed to increase the probability of program success using these elements.

Table 1 – Steps to building a risk adjusted Performance Measurement Baseline with Management Reserve.

Step	Outcome
Define WBS	▪ Using SOW, SOO, ConOps, and other program documents, develop WBS for system elements and work processes that produce the program outcomes. ▪ Develop WBS Dictionary describing the criteria for the successful delivery of these outcomes.
Build IMP	▪ Develop Integrated Master Plan, showing how each system element in the WBS will move through the maturation process at each Program Event. ▪ Define Measures of Effectiveness (MOE) at each Accomplishment (SA). ▪ Define Measures of Performance (MOP) at each Criteria (AC).
Identify Reducible Risks	▪ For each key system element in the WBS, identify reducible risks, probability of occurrence, mitigation plan, and residual risk in the Risk Register. [5][4] ▪ Risk mitigation activities will be placed in the Integrated Master Schedule (IMS). [20] ▪ For risks without mitigation plans, place budget for risk in Management Reserve (MR) to be used to handle risk when it becomes an Issue.
Build IMS	▪ Arrange Work Packages and Tasks in a logical network of increasing maturity of system elements. [11] ▪ Define exit criteria for each Work Package to assess planned Physical Percent Complete to inform BCWP with TPM, MOP, MOE, and Risk Reduction assessments.

[†] This article was contributed by the College of Performance Management (CPM), an international association for those engaged in earned value management, project cost and schedule control, program management and program/project performance management. For information about CPM, visit their website at https://www.mycpm.org/

‡ The term *…"ilities"* refers to terms such as maintainability, reliability, serviceability, operability, testability, etc. [**Error! Reference source not found.**]

Identify Irreducible Risks	▪ For irreducible risks in the IMS, use Reference Classes for Monte Carlo Simulation anchored with Most Likely duration to calculate needed schedule margin. ▪ Assign schedule margin to protect key system elements, per DI-MGMT-81861 guidance.
Baseline PMB	▪ Using risk adjusted IMS containing reducible risk and explicit schedule margin tasks, establish the Performance Measurement Baseline (PMB) and calculate the Management Reserve (MR). ▪ Management Reserve is used for unmitigated risks that remain in the risk register.

THE SITUATION

We're working ACAT1/ACAT2 programs for Department of Defense using JCIDS (Joint Capabilities and Development Systems) the governance guidance defined in DODI 5000.02.

The JCIDS *Capabilities Based Planning* paradigm tells us to define what *Done* looks like in units of Effectiveness and Performance, so we need to start by measuring progress toward delivered Capabilities. Requirements elicitation is part of the process, but programs shouldn't start with requirements, but with an assessment of the *Capabilities Gaps*. While this approach may seem overly formal, the notion of defining what capabilities are needed for success is the basis of defining what *Done* looks like. We'll use this definition, so we'll recognize it when it arrives.

With the definition of *Done*, we can define the processes for incrementally assessing our system elements along the path to *Done*. Earned Value Management is one tool to perform these measurements of progress to plan. But like it says in EIA-748-C, Earned Value – left to itself – is a measure of quantity. We need measures of quality and other *…ilities* that describe the effectiveness and performance of the product to inform our Earned Value measures of the Estimate to Complete (ETC) and Estimate at Completion (EAC).

We need to integrate other measures with the Earned Value assessment process. We can start this by recognizing that the Budgeted Cost of Work Performed (BCWP) is a measure of the efficacy of our dollar.

Earned Value is actually the measure of "earned budget." Did we "earn" our planned budget? Did we get our money's worth? We only know the answer if we measure "Value" in units other than money. This can be the effectiveness of the solution, the performance of the solution, the technical performance of the products, or the fulfillment of the mission. The maintainability, reliability, serviceability, and other *…ilities* are assessments of *Value* earned, not described by CPI and SPI from the simple calculation of BCWP.

THE IMBALANCE

Without the connection between the technical plan and programmatic plan – cost and schedule – the program performance assessment cannot be credible. [3] Of course BCWP represents the *Earned Value*, but the Gold Card and other guidance don't explicitly state how to calculate this number. BCWP is a variable without directions for its creation. BCWS and ACWP have clear direction on how to assign values to them, but not BCWP.

The common advice is to determine *percent done* and then multiply that with BCWS to produce BCWP. But what is the *percent done* of what outcome? What units of measure are used to calculate *percent complete*?

It's this gap between just assigning a value to BCWP through Earned Value Techniques (EVT) and informing BCWP with tangible evidence of progress to plan, in units of measure meaningful to the decision makers, that is the goal of this paper.

RESTORING THE BALANCE

Balance is restored by starting with the target values for Effectiveness, Performance, *…illities*, and level of acceptable Risk at specific times in the program – at Program Events – measure the actual Effectiveness, Technical Performance, *…illities*, and Risk, to produce a variance, to determine the physical percent complete of any system elements in the WBS.

Using the steps in **Table 1** and elements of **Figure 1** the connections between each element assure the Technical Plan and the Programmatic Plan are integrated with units of performance needed to inform BCWP.

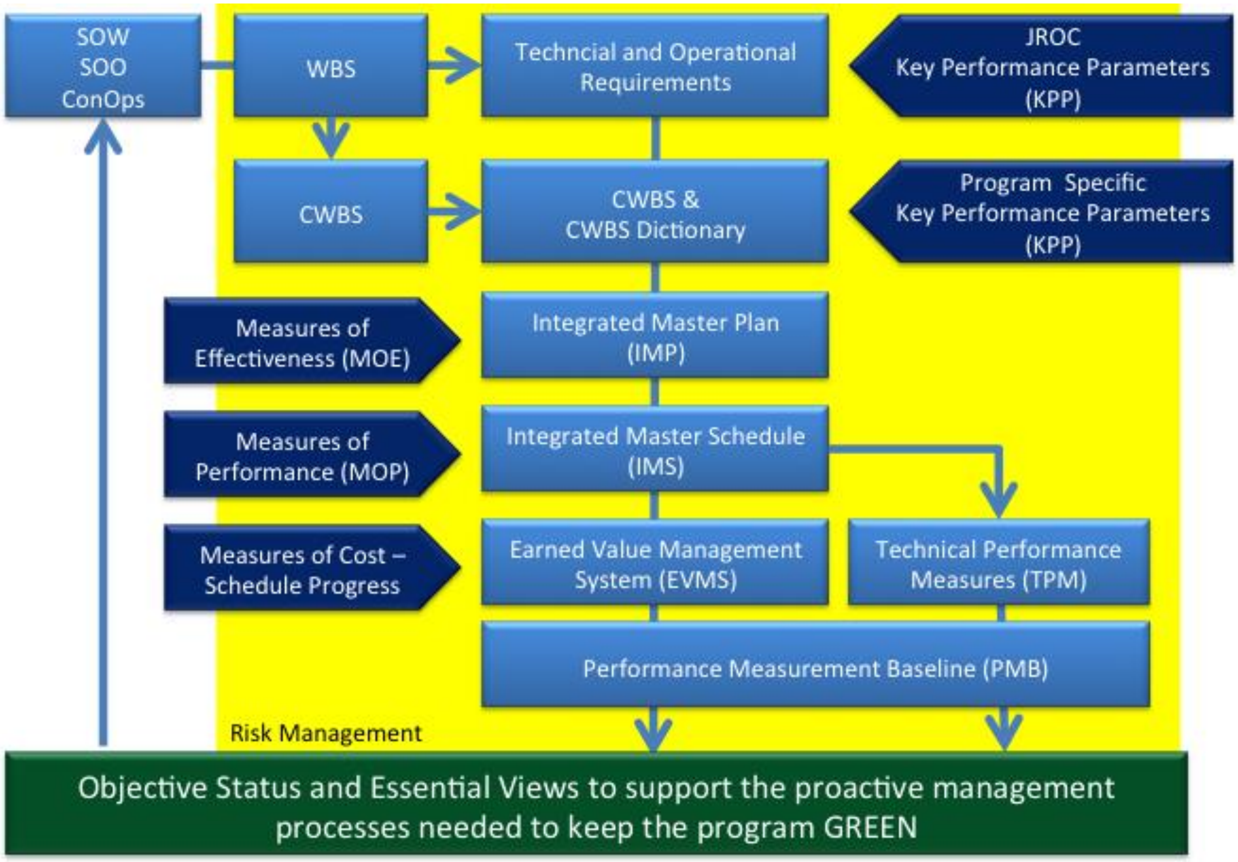


Figure 1 – Programmatic elements needed to increase the probability of program success. Connecting the dots between Measures of Effectiveness, Measures of Performance, and Technical Performance Measures needed to inform BCWP that provide leading indicators of performance needed to take corrective actions to Keep The Program GREEN.

The remainder of this paper describes the steps needed to establish a credible PMB containing event-based risk reduction activities and schedule margin for irreducible risks. Both are needed to assure the necessary probability of success for cost, schedule, and technical performance. These steps include:

- Identifying the reducible risks and their mitigation plans and placing these in the IMS.
- Identifying the Measures of Effectiveness, Measures of Performance, Technical Performance Measures, and Key Performance Parameters and assigning them to IMP and IMS elements.

- Baselining the IMS and developing a Monte Carlo Simulation model of the Irreducible Risks with the needed schedule and cost margins to protect delivery dates and baselined budget.

THE SOLUTION

Creating a credible PMB and successfully executing the program, starts by *connecting the* dots between the processes in **Table 1**, and the elements in **Figure 1**. This ensures the program's Technical Plan and the Programmatic Plan are integrated from day one. Making these connections starts with Systems Engineering – where the MOEs, MOPs, TPMs, the *…ilities*, and Risk are identified. These target values are flowed onto the IMP and IMS and used to create work activities for reducible risks, and appropriate schedule margins identified through Monte Carlo Simulations needed for margins to address the irreducible risks. There is existing guidance in place, starting at the Government Program Management Office, down to the contractor level to guide the development of these connections.

But to restate it again, it can't be any clearer than this …

1.2.1 Integrate cost and schedule performance data with objective techncial measures of performance.

DI-MGMT-81861

WORK BREAKDOWN STRUCTURE IS PARAMOUNT

The path to creating a credible PMB starts with the Work Breakdown Structure. It is in the WBS that the system elements are defined, as well as the processes that produce the system elements, and the risk to the performance of these system elements.

MIL-STD-881-C Guidance [6]

The Work Breakdown Structure, described in MIL-STD-881-C, has several purposes that support the development of our credible PMB. [13]

- DoD Directive 5000.01 — The Defense Acquisition System — requires a disciplined approach in establishing program goals over its life cycle with streamlined and effective management that — is accountable for credible cost, schedule, and performance reporting.
    - The WBS is a critical tool in ensuring all portions of the program are covered. This all-in requirement assures all system elements are identified in the WBS.
    - The WBS facilitates collaboration between the Integrated Product Teams by connecting performance, cost, schedule, and risk information in the IMP, IMS, and Risk Register.
    - The WBS facilitates the technical rigor and integrated development, test, and evaluation throughout the acquisition process.
    - The WBS is the first location to define the risks to achieving the above items in this list.
- DoD Instruction 5000.02 — *Operation of the Defense Acquisition System* — further outlines the required framework and provides impetus for use of a WBS.

- The evolution of the system through incremental development further drives the requirement to breakdown the system in a structure that clarifies which capabilities will be satisfied in a specific increment of the system development.
- The instruction sets the requirements for Integrated Master Schedules (IMS), Earned Value Management (EVM) and other statutory, regulatory, and contract reporting information and milestone requirements in which the WBS is a critical element.

- The final *dot* to be connected is the critical link between the WBS, IMP, and IMS with the Systems Engineering Plan (SEP) on the government side and the Systems Engineering Management Plan (SEMP) on the contractor side. These are where MOEs, MOPs, KPPs, Risks, and TPMs start and are connected with the assessment of Physical Percent Complete.

Risk Management Starts At The WBS

Just like DODI 5000.01 tells us to start with the WBS for risk identification, the Defense Acquisition Guide also states:

> *Risk is a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule, and performance constraints. Risk can be associated with all aspects of a program (e.g., threat environment, hardware, software, human interface, technology maturity, supplier capability, design maturation, performance against plan,) as these aspects relate across the Work Breakdown Structure and Integrated Master Schedule.*

With the guidance shown above, **Figure 1** shows WBS is the first place the program encounters risk management along with their identification and the description of their outcomes, in the WBS Dictionary.

Each key system element in the WBS must be assessed for technical or programmatic risk that will impede its delivery on time, on cost, and on performance. The reduction of this risk, following its planned risk reduction levels, will be used to inform Physical Percent complete and the resulting BCWP. If risk is not being reduced as planned, the program's Earned Value measures may not properly represent the technical progress.

THE INTEGRATED MASTER PLAN (IMP)

The IMP is an event-based plan consisting of a sequence of program events, with each event being supported by specific accomplishments, and each accomplishment associated with specific criteria to be satisfied for its completion. These IMP elements are defined as: [1], [2], [3], [10]

- **Event**: a key decision point or program assessment point that occurs at the culmination of significant program activities.
- **Accomplishment**: is the desired result(s) prior to or at completion of an event that indicates a level of the program's progress.
- **Criteria**: provides definitive evidence that a specific accomplishment has been completed. Entry criteria reflect what must be done to be ready to initiate a review, demonstration, or test. Exit criteria reflect what must be done to clearly ascertain the event has been successfully completed.

Structure of the Integrated Master Plan (IMP)

Figure 2 shows the structure of the Integrated Master Plan (IMP), with Program Events (PE), Significant Accomplishments (SA), and Accomplishment Criteria (AC). This structure assesses the increasing maturity of each key system element, to assure the end item system elements meet the planned Effectiveness and Performance needs that fulfill the capabilities for the mission or business goals. [14][15]

With this structure, Earned Value Management measures can now be connected to the Work Packages defined in the Integrated Master Schedule (IMS) to assess technical performance in ways not available with CPI and SPI only. The Program Manager now has leading indicators of the program success through the MOEs defined by the SA's and MOPs defined by the AC's, each assessed for compliance with plan at the Program Event. In **Figure 2** the IMS should encompass the IMP; work packages and tasks are the "new" element the IMS adds to the IMP along with the element of time.

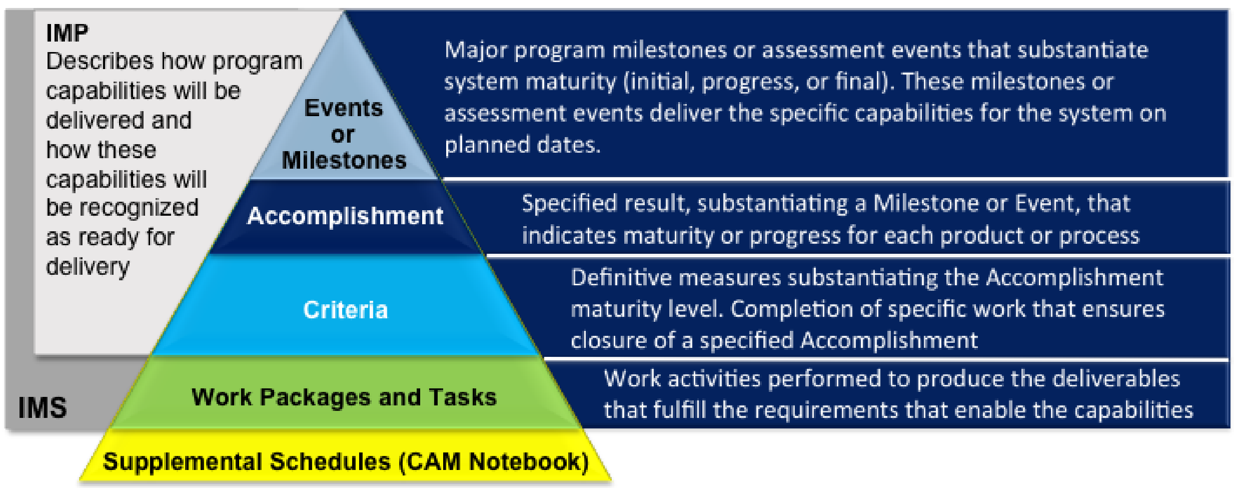


Figure 2 – The Integrated Master Plan defines the increasing maturity of each key system element assessed at Program Events. Significant Accomplishments are entry criteria for this maturity assessment. Accomplishment Criteria are measures substantiating the maturity level of the work products produced by Work Packages in the IMS.

Measures of "Progress To Plan" Start At The IMP

The Program Events, Significant Accomplishments, and Accomplishment Criteria form the elements of the IMP. Measures of Effectiveness (MOE) for the program are derived from the JCIDS process and are reflected in the IMP's Significant Accomplishments (SA). The Measures of Performance (MOP) are derived from the MOEs and are reflected in the IMP's Accomplishment Criteria (AC).

These measures assess the physical percent complete of the system elements used to inform Earned Value (BCWP) for reporting programmatic performance. With this Physical Percent Complete measure, the EVM indices then reflect the cost, schedule, and technical performance of the program using the Systems Engineering measures:

- **Measures of Effectiveness** (MOE) – are operational measures of success closely related to the achievements of the mission or operational objectives evaluated in the operational environment, under a specific set of conditions.
- **Measures of Performance** (MOP) – characterize physical or functional attributes relating to the system operation, measured or estimated under specific conditions.

- **Key Performance Parameters** (KPP) – represent significant capabilities and characteristics in that failure to meet them can be cause for reevaluation, reassessing, or termination of the program.
- **Technical Performance Measures** (TPM) – are attributes that determine how well a system or system element is satisfying or expected to satisfy a technical requirement or goal. [22]

Continuous verification of actual performance versus anticipated performance of a selected technical parameter confirms progress and identifies variances that might jeopardize meeting a higher-level end product requirement. Assessed values falling outside established tolerances indicate the need for management attention and corrective action.

A well thought out TPM process provides early warning of technical problems, supports assessments of the extent to which operational requirements will be met, and assesses the impacts of proposed changes made to lower-level elements in the system hierarchy on system performance. [§] With this estimate, the programmatic performance of the program can be informed in a way not available with CPI and SPI alone.

Technical Performance Measurement (TPM), as defined in industry standard, EIA-632, involves estimating the future value of a key technical performance parameter of the higher-level end product under development, based on current assessments of products lower in the system structure.

Continuous verification of actual versus anticipated achievement for selected technical parameters confirms progress and identifies variances that might jeopardize meeting a higher-level end product requirement. Assessed values falling outside established tolerances indicate the need for management attention and corrective action.

Risk Management Continues From The WBS To The IMP

Throughout all product definition processes, technical and programmatic risk assessment is performed. These risks are placed in the Risk Register shown in **Figure 3** with their uncertainties. Uncertainty comes in two forms: [**]

Table 2 – Irreducible and Reducible uncertainty both create risk to the program for cost, schedule, and technical performance. As well as reducible and irreducible there are Unknown Unknowns that are mitigated in the DOD by replanning the program. [19]

Reducible Uncertainty	Irreducible Uncertainty
The probability that something will happen to impact cost, schedule, and technical performance of the system elements.	***The natural variation of the program's activities work duration and cost. The variance and its impacts are protected by schedule and cost margin.***
▪ Reducible uncertainty can be stated as the probability of an event, and we can do something about reducing this probability of occurrence. ▪ These are (subjective or probabilistic) uncertainties that are event-based probabilities, are knowledge-based, and are reducible by	▪ Irreducible uncertainty is the probability range of these variances of the stochastic variability from the natural randomness of the process and is characterized by a probability distribution function (PDF) for their range and frequency, and therefore are irreducible. ▪ Irreducible uncertainty can be modeled with

§ https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=7c1d9528-4a9e-4c3a-8f9e-6e0ff93b6ccb

** "On Numerical Representation of Aleatory and Epistemic Uncertainty," Hans Schjær-Jacobsen, *Proceedings of 9th International Conference of Structural Dynamics*, EURODYN 2014.

further gathering of knowledge.	Monte Carlo Simulation using Reference Classes based on past performance.

Capture Reducible Risks Through the WBS Number

With Reducible risks, specific work is performed *on baseline* to reduce the probability of occurrence or impact or consequence of the risk. [5] With Irreducible risk, schedule margin is needed to protect the delivery date of key system elements. A measure of the performance of the program is the Margin Burn-down Plan shown in **Figure 8.** If the actual risk reduction does not follow the risk burn-down plan, this is a leading indicator of future difficulties in the program's performance and an indicator of impact on cost and schedule.

ID No.	Risk Title	Initial Risk	Risk at ATP	Risk at PDR	Risk Type	WBS
	Center-of-Gravity Limits	16	15	10	Technical	2.1.5
	Gross Liftoff Weight	16	15	10	Technical	2.1.5
	Flight- & Mission-Critical Software Development Effort	16	11	10	Schedule	2.1.4
	Development	16	12	8	Schedule	6.2.14
	Achieving Component-, Subsystem- & System-Level Qualification	15	14	11	Schedule	2.1.7
	Production	12	12	10	Schedule	6.5
	Autonomous Rendezvous & Docking Development	12	10	9	Schedule	6.2.12
	Thermal Protection System Development	12	10	7	Technical	6.2.5
	Landing/Impact Attenuation	12	12	6	Technical	6.2.11
	Recover/Landing System (RLS) Rigging Complexity	12	12	6	Technical	6.2.11
	Space Qualification of EEE Parts	12	10	4	Schedule	2.1.9.3
	Uncertain Implementation To Achieve a Human-Rated Hardware/Software System	12	8	3	Schedule	2.1.8

Legend: Low risk (≥1 to ≤ 6) Moderate risk (> 6 to < 15) High risk (≥15)

Figure 3 – The mitigation activities for Reducible are guided by the Risk Register's contents and the WBS in the IMS. Work to reduce risk is planned and executed *On Baseline* through Work Packages. Risk reduction lowers the probability and/or impact of occurrence and therefore lowers the probability of impact of the named risk.

STEPS TO BUILDING A CREDIBLE INTEGRATED MASTER PLAN

The Integrated Master Plan (IMP) is the strategy for the successful delivery of outcomes of the program. Strategies are *hypotheses* that need to be tested. The IMP's Events, Accomplishments, and Criteria are the *testing points* for the hypothesis that the program is proceeding as planned, both technically as planned and programmatically as planned. Development of the IMP is a step-wise process, starting with the Program Events.

Identify Program Events

Program Events are maturity assessment points. They define the needed levels of maturity for the products and services before proceeding to the next assessment point. The entry criteria for each Event define the units of measure for the successful completion of the Event.

The Program Events confirm the end-to-end description of the increasing maturity of the program's system elements. As well, they establish the target dates for each Event in the RFP or contract.

Finally they socialize the language of speaking in "Increasing Maturity at Events" rather than the passage of time and consumption of budget.

Identify Significant Accomplishments

The Significant Accomplishments (SA) are the "road map" to the increasing maturity of the program. They are the "Value Stream Map" resulting from the flow of SA's describing how the products or services move through the maturation process while reducing risk. This Significant Accomplishment map is our path to "done".

Identify Accomplishment Criteria

The definition of "done" emerges in the form of system elements rather than measures of cost and passage of time. These system elements come from Work Packages, whose outcomes can be assessed against Technical Performance Measures (TPM) to assure compliance with the Measure of Performance (MOP). At each Program Event, the increasing maturity of the system elements is defined through the Measures of Effectiveness (MoE) and Measures of Performance (MoP).

The vertical connectivity of ACs and SAs to PEs, described in **Figure 4**, establishes the framework for the horizontal traceability of Work Packages in the Integrated Master Schedule to the Integrated Master Plan.

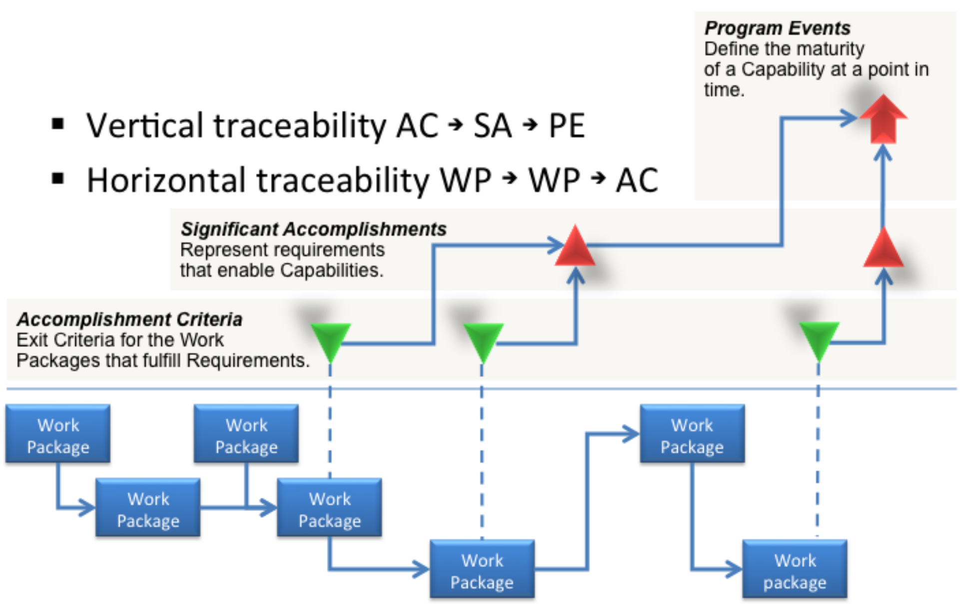


Figure 4 – Vertical and horizontal traceability between the Integrated Master Plan (IMP) and the Integrated Master Schedule (IMS). The IMP describes how the increasing maturity of the system elements will be assessed with Measures of Effectiveness (MOE) and Measures of Performance (MOP). The IMS describes the work needed to produce that increasing maturity through the assessment of Technical Performance Measures (TPM).

INTEGRATED MASTER SCHEDULE (IMS)

The Integrated Master Schedule (IMS) embodies all work effort needed to produce a product or accomplish specific goals that have an associated cost. The work effort is represented by well-defined tasks that program participants execute (expending cost) to generate the desired products. [12]

Tasks are organized in the proper sequence to facilitate efficient execution that enables the program to know what work must be accomplished to achieve their objectives. Task sequencing occurs by recognizing the dependencies among all the tasks. Then, by identifying the expected time to perform each task, the program can project an expected completion time. [3] A well-structured and managed IMS can now serve as the program's GPS, providing timely information that enables program management to making informed decisions about the paths to successful delivery of all the system elements.

The IMP Events, Accomplishments, and Criteria are duplicated in the IMS. Detailed tasks are added to depict the steps required to satisfy performance criterion. The IMS should be directly traceable to the IMP and should include all the elements associated with development, production or modification, and delivery of the total product and program high level plan.

Durations are entered for each discrete task in a work package, planning package, and lower level task or activity, along with predecessor and successor relationships, and any constraints that control the start or finish of each work package and planning package.

The result is a fully networked "bottoms up" schedule that supports critical path analysis. Although durations are assigned at the work package and planning package level, these durations will roll up to show the overall duration of any event, accomplishment, or criteria. When Level of Effort (LOE) work packages, tasks, or activities are included in the IMS, they must be clearly identified as such. Level of Effort shall never drive the critical path.

STEPS TO BUILDING THE INTEGRATED MASTER SCHEDULE (IMS)

Starting with the WBS, a credible IMS that produces the system elements must address reducible risk through risk mitigation activities. This IMS must also address the irreducible uncertainties and those discrete risks that remain in the risk register that could not be mitigated through work activities. These uncertainties are categorized as known–unknowns because they are known, but it is not known for certainty that they will occur.

Programs can protect against these uncertainties by setting cost and schedule margin for the irreducible uncertainties, and management reserves for the reducible risks that were not mitigated. Cost and schedule margins are included in the Performance Measurement Baseline and Management Reserve is established for the latent reducible risks and is held above the PMBs but is still part of the Contract Budget Base (CBB).

REDUCIBLE RISK MANAGEMENT PROCESSES ARE IN THE IMS

All reducible risks identified in the Risk Register need to be assessed for *reducibility* in the IMS. If the risk – the uncertainty that is event based – can be reduced, then that work is assigned to work packages and activities in the IMS and placed on baseline. These *risk buy down* activities are managed just like ordinary work, funded by the CBB, and measured for performance just like any other work.

The risk reduction mitigation activities are planned to achieve a specific level of risk reduction at a specific time in the IMS. Meeting the planned risk reduction level at the planned time is a measure of performance of the risk retirement activities.

IRREDUCIBLE RISK MANAGEMENT PROCESSES ARE IN MARGIN

With the reducible risks from the Risk Register handled with risk retirement activities in the IMS, the irreducible risks now need to be identified and handled in the IMS. Since the irreducible risks are actually *irreducible*, only margin can be used to protect the system elements from this naturally occurring variance. No actual work can be done to do this.

Monte Carlo Simulation of the IMS is the primary tool for assessing how much margin is needed for each irreducible risk type.

DEVELOPMENT OF SCHEDULE MARGIN

Schedule margin is a buffer of time used to increase the probability that the program will meet the targeted delivery date. Schedule Margin is calculated by starting with a Probability Distribution Function (PDF) of the naturally occurring variance of the work duration of the *Most Likely* value of that duration. With the *Most Likely Value* and the PDF for the probability of other values, the durations of all work in the Integrated Master Schedule and the probabilistic completion times of this work can be modeled with a Monte Carlo Simulation tool. [9]

This modeling starts with the deterministic schedule, which includes work for the Reducible Risks. The schedule margin is the difference in the initial deterministic date and a longer duration and associated date with a higher confidence level generated through the Monte Carlo Simulation.

Figure 5 illustrates this concept. In this example, the deterministic delivery date is 8/4/08 with the contract delivery date of 8/31/08. Using the historical variability of the task durations resulted in a 5% confidence level of completing *on or before* 8/4/14 shown in the deterministic schedule. This says that with the deterministic schedule – no accounting for the natural variability in work durations, the probability of completing on or before 8/4/08 is 5%. [††]

To increase the confidence level of meeting the contractual date, the contractor needs to increase the probability of completing *on or before* to 80%. The difference in duration between the deterministic schedule's completion date of 8/4/08 and the 80% confidence of completing *on or before* 8/14/08 is 10 calendar days, still earlier than the contractual date of 8/31/08.

[††] These dates are taken from the Wright Brothers development efforts of the *Heavier-Than-Air* contract issued by the U.S. Army at the turn of the twentieth century. This example will be used later in this paper to show how to *connect all the dots* to produce a credible PMB.

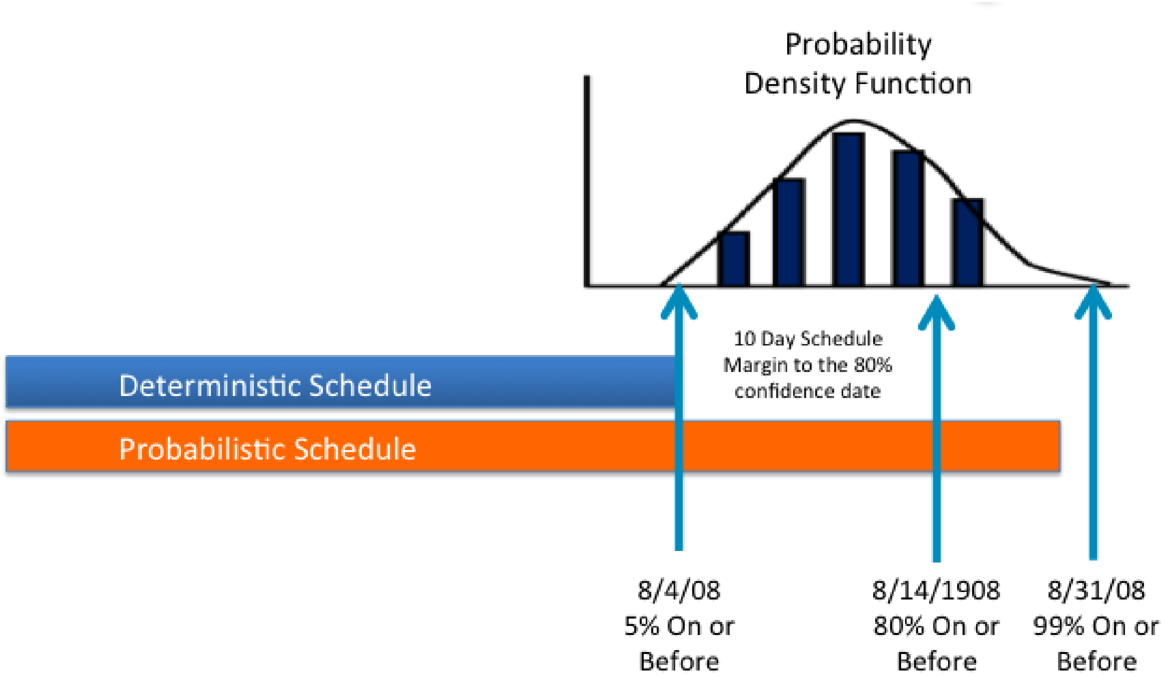


Figure 5 – Monte Carlo Simulation used to determine schedule margin developed from the Deterministic IMS, showing a completion date of 8/4/08. The 80% confidence of completing *on or before the* needed 8/14/08. The Schedule Margin is then added in front of key system elements to protect their delivery dates to meet the contractual need date of 8/31/08

Assign Schedule Margin to Protect Key System Elements

Using schedule margin to protect against schedule risk – created by the natural uncertainties in the work durations enables on-time contractual end item deliveries.

There are two schools of thought on how schedule margin should be managed.

- Place all schedule margin at the end of the program or system elements.
- Distribute margin at strategic points along critical paths where there are known schedule risks.

Placing all the margin at the end appears effective in short duration or production efforts where the primary schedule risk is not driven by technical complexity. The same objective can be achieved when a disciplined process is followed for control and consumption of distributed margin. Paramount to this approach is accelerating downstream efforts when margin is NOT consumed.

Most schedule risk in a development program is encountered when program elements are integrated and tested. Even when margin is distributed, margin is often kept at the end of the schedule to help protect against risk when all paths come together during final integration and test. This approach enables on-time end item delivery with realistic cost and schedule baselines that provide accurate forecasts and decisions based on current status, remaining efforts and related schedule risks.

There are several valid reasons for distributing schedule margin earlier in the IMS including:

- Protecting use of critical shared resources so that being a few weeks late doesn't turn into a several month schedule impact. An example in space programs is use of a thermal vacuum chamber shared across multiple programs at critical times in their schedules. If a program is unable to enter the chamber at their scheduled time the ultimate delay may be an exponential factor of their original delay.
- Protecting highly visible milestones that are difficult and undesirable to change like a Critical Design Review (CDR).
- Establishing realistic performance baselines accounting for schedule risk at key points provides more valid data to make program decisions.
- Establishing realistic baselines that are cost effective.
- Placing margin where we believe it will be needed and consumed provides the most realistic schedule baseline possible for succeeding efforts and enables more accurate resource planning for prime contract, customer, and suppliers.

Key Insertion Points for Schedule Margin

Schedule Margin is not the same as Schedule Slack or Schedule Float as stated in the GAO Schedule Assessment Guide. [‡‡] Margin is preplanned and consumed for known schedule irreducible uncertainty and float is the calculated difference between early and late dates. In many ways margin is much like management reserve and float is similar to underruns/overruns.

- Schedule margin is placed where there is known irreducible schedule risk. It is never consumed because of poor schedule performance. In this case, Schedule Margin is managed like Management Reserve.
- Schedule margin is not budgeted – it does not have an assigned BCWS. If the risk the margin is protecting comes true, new tasks need to be identified and budgeted. If the risk is not realized, the schedule margin is zeroed out and the succeeding tasks accelerated – *moved to the left*.
- Allocating margin for known risks at key points prevents this margin from being used to cover poor schedule performance. This forces an immediate recovery action to stay on schedule instead of degrading margin as if it was schedule float.
- Inclusion of margin – either distributed in front of key system elements or at the end of contractual system elements – does not affect contractual period of performance. The period of performance is defined by the contract. The Schedule Margin activities in the deterministic schedule are represented in the PMB, using the task label defined in DI-MGMT-81861 §3.7.2.4 – SCHEDULE MARGIN.
- Inclusion of schedule margin for known schedule risk provides a realistic baseline and accurate resource planning (including the customer). If not consumed the effort is accurately represented as "ahead of schedule".

‡‡ GAO Schedule Assessment Guide, page 113. "Schedule margin is calculated by performing a schedule risk analysis and comparing the schedule date with that of the simulation result at the desired level of uncertainty."

Development of Cost Margin or Contingency Reserve

The cost margin is the amount of cost *reserve* needed to address irreducible cost variances of the program's work efforts and to improve the probability of meeting the target cost – the contract cost. Cost margin is calculated in the same manner as schedule margin. The contractor develops a probability distribution of the final cost based on the natural variances contained in the historical databases. The confidence level of meeting the target contracted cost in the IMS is noted. If the confidence level is too low, it has been suggested that cost margin be added to the baseline, in the same manner as schedule margin, to bring the baseline up to a desired cost confidence level.

However, at this time, there is no generally agreed to mechanism to do so. If the Confidence Level is unacceptably low, the contractor must redo the IMS and try to reduce costs for time dependent and time independent costs to raise the cost confidence to an acceptable level. Re-planning would result in re-calculating the schedule margin. If after re-planning, the cost confidence level is still unacceptably low, the contractor should report the Confidence Level to the customer at the time of the Integrated Baseline Review (IBR). If the customer agrees the Confidence Level is too low, resources could be added and the contractor would update the IMS, or the contract could be de-scoped to improve the Confidence Level. Alternatively, the customer may hold the cost margin as a contingency for overruns.

Development of Management Reserves

Management Reserves are financial resources needed to address the reducible risks that were not mitigated. The optimal way to develop management reserve is to re-run the Monte Carlo Simulation tool with only these risks against the resource-loaded IMS. The difference between the deterministic cost estimate and the point on the cost distribution curve for the desired cost confidence level is the Management Reserve.

EXECUTING THE BASELINED PROGRAM

To inform Earned Value (BCWP), we need information about the performance of the program beyond just cost and schedule performance. We need information about how the program is progressing toward delivering the needed capabilities. How are these capabilities being fulfilled as the program progresses? What risks are *bought down* at the planned time to increase the probability of success? How are the Technical Performance Measures being assessed compared to the planned measures needed to deliver the needed capabilities?

Connecting the Dots to Execute The IMS

Some reminders from DOD guidance are needed before starting to connect the dots. Connecting cost, schedule, and technical performance is the basis of program success. Without these connections the Earned Value measures cannot be informed by the technical performance. Also, the Earned Value measures are simply a reflection of the passage of time and consumption of resources, with no connection to the planned technical maturity of the program's system elements. Three measures of program performance are used to inform Earned Value. [8]

- Programmatic and Technical Performance Measures, **Figure 7**
- Risk retirement burn down, **Figure 8**

- Schedule margin utilization, **Figure 9**

With the MOEs, MOPs, KPPs, Risks and their reduction plans, and the TPMs assigned to the IMP and IMS, we have all the pieces to *connect the dots.*

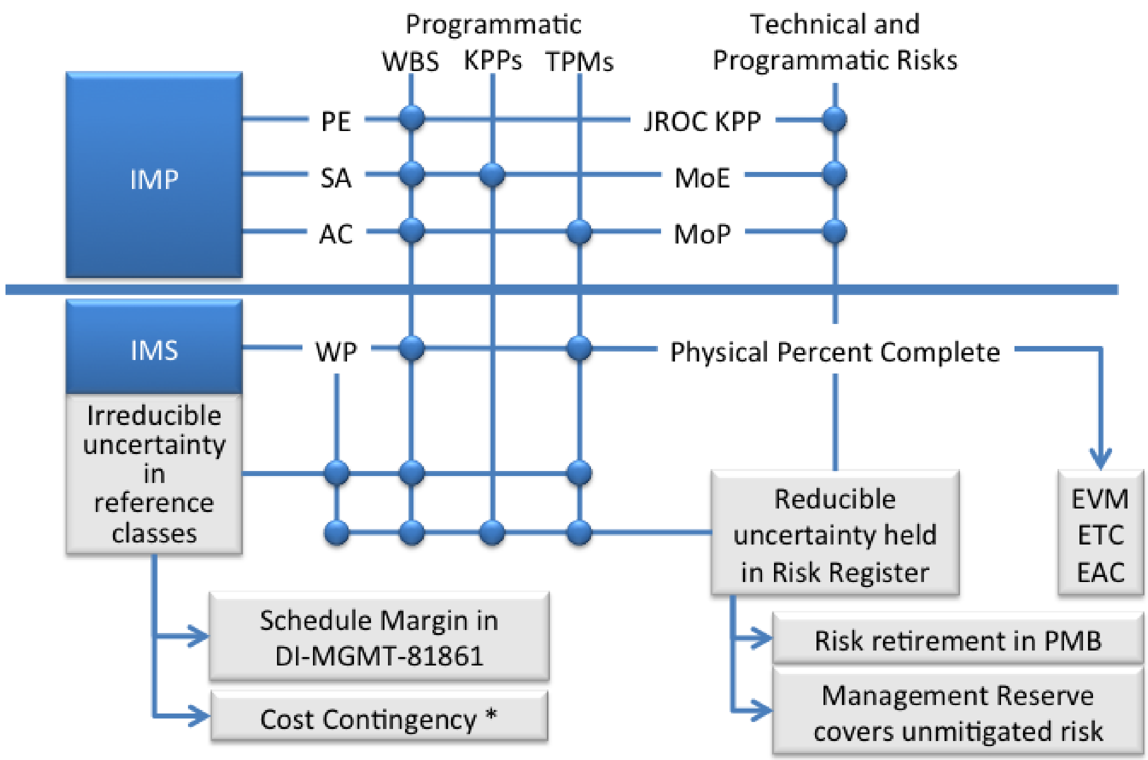


Figure 6 – Starting with the IMP and the measures of progress to plan at the Program Event, Significant Accomplishment, and Accomplishment Criteria levels, the IMS is constructed and work performed in Work Packages can be assessed as Physical Percent Complete in units of measure meaningful to the decision makers.

Programmatic And Technical Measures Inform Earned Value

Our ultimate purpose for this paper was to lay the groundwork for developing a credible Performance Measurement Baseline, and to use that baseline to increase the probability of program success. The first question that comes up is – what is credible?

Increasing fidelity of program performance

	Operational definition of Credible, means …	Units	Docs
6	Compliance with Planned JROC Key Performance Parameters at each stage of program maturity in units of mission effectiveness	KPP	CBP
5	Compliance with Planned Program Key Performance Parameters for each deliverable at each stage of program maturity	KPP	SOW
4	Compliance with Planned Measures of Effectiveness (MoE) for each deliverable at each stage of program maturity	MOE	IMP
3	Compliance with Planned Measures of Performance (MoP) for each deliverable at each stage of program maturity	MoP	IMP
2	Probabilistic EAC using EV Data, TPMs, and Risks and probabilistic forecasting models	EAC, TPM, RR	PMB
1	Earned Value Data derived from risk adjusted past performance	EV	PMB

Figure 7 – Technical Performance Measures, Measures of Performance, Measures of Effectiveness, and Key Performance Parameters assure the delivered products are not only *Fit for Purpose* (Technically compliant) but also *Fit for Use* (Meet the needed Mission Capabilities).

Risk Retirement as a Measure of Program Performance

BCWP can be informed with the performance of the planned retirement processes on the planned day for the planned cost, to the planned risk level. The work activities of risk reduction are no different than work activities needed to produce system elements. They are on baseline, produce outcomes and have technical assessment of their progress to plan.

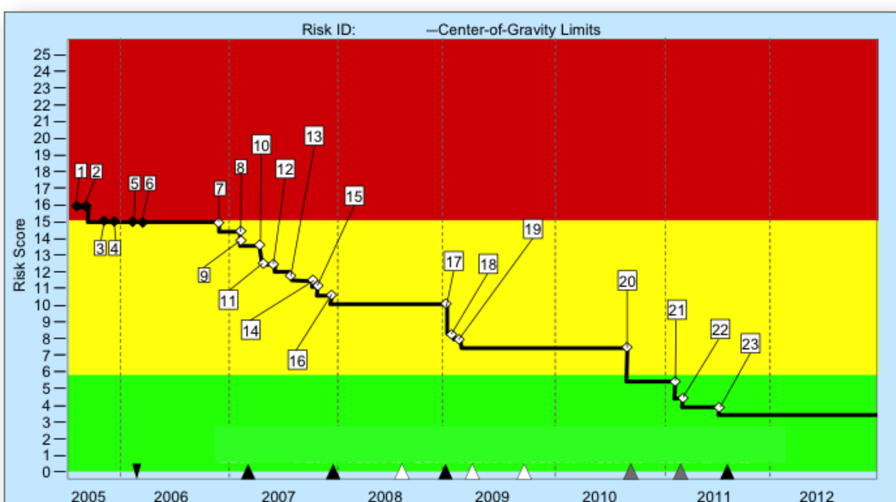


Figure 8 – The planned risk reduction in the Center Of Gravity going out of bounds for a flight vehicle as a function of time in the Integrated Master Schedule. Baseline work is performed to reduce this risk and therefore reduce the impact of the risk. Making the reductions to the planned level on the planned day informs the BCWP of the Earned Value numbers. Reducing the risk late must reduce the BCWP for activities related to the risk.

Schedule Margin Burn-Down is a Measure of Program Performance

Schedule Margin is a duration buffer prior to a system element delivery date or any contract event. As a project progresses, the length of the schedule margin task is re-evaluated and adjusted as needed to protect the system elements from risks of delay that result from natural variances in work effort durations. The Schedule Margin Burn Down shown in **Figure 7**, displays the use of schedule margin over time. Schedule Margin compensates for work activity duration uncertainties. As a program progresses, the total schedule margin is re-evaluated and adjusted to protect the system elements from risks that arise from natural variances in duration.

When Schedule Margin is used faster than planned, this indicates cost and schedule progress is at risk, since uncertainty has not been controlled as planned. [21]

The identified schedule margin can then be used to inform program performance by comparing planned schedule margin with actual schedule margin.

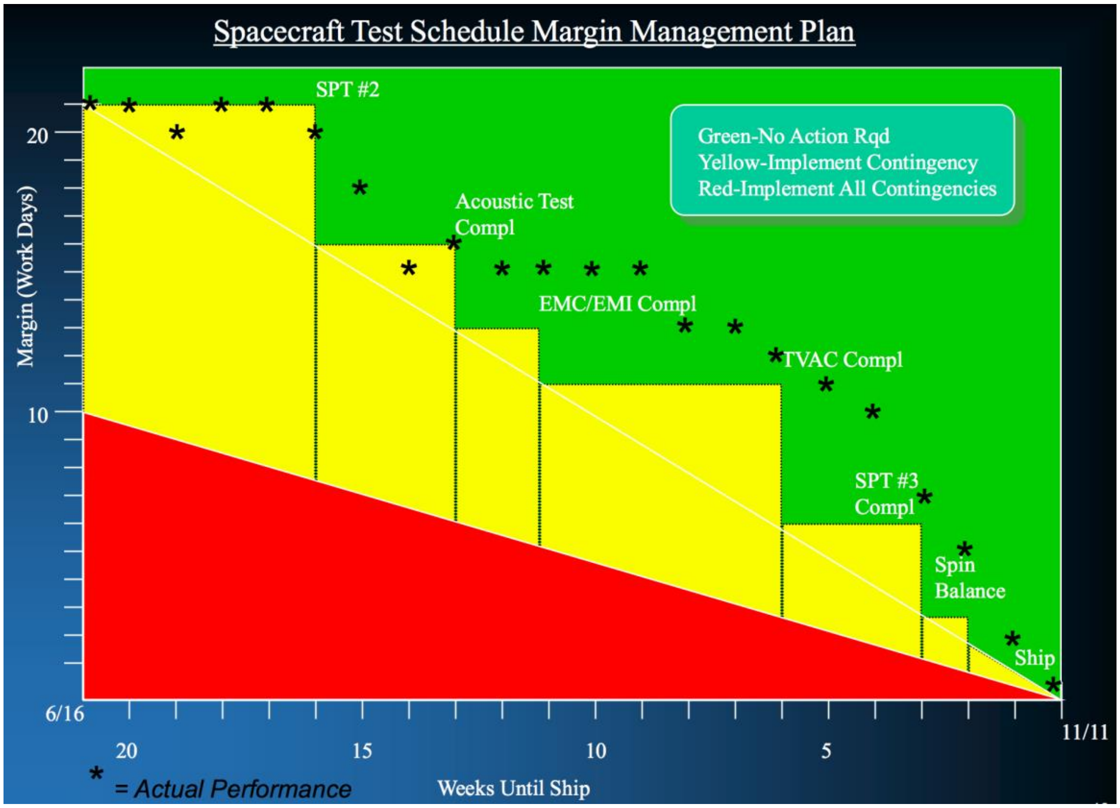


Figure 9 – Schedule Margin Burn-Down Plan depicts the planned schedule margin versus the actual schedule margin consumption that protects the date of a key system element. Status against this schedule margin plan is a leading indicator of the risk to the delivery date and the success of the program. [8]

NOW A PRACTICAL EXAMPLE

Let's start with a practical example we can all recognize. Immediately after the Wright Brothers made their first powered flights in 1903, they begin to develop their experimental aircraft into a marketable product.

By 1905 they had the basis of a "practical flying machine." Other experimenters learned of their work and begin to build on their success.

By 1906, others pilots were making tentative hops in uncontrollable aircraft. By 1909, after watching the Wrights' flying demonstrations, they grasped the brilliance and necessity of three-axis aerodynamic control. The performance of their aircraft quickly caught up to and then surpassed Wright Flyers. The capabilities of and the uses for aircraft expanded as designers and pilots introduced float planes, flying boats, passenger aircraft, observation platforms fitted with radios and wireless telegraphs, fighters, and bombers. [18]

Figure 10 – the Wright Flyer on its flight trials at Fort Myer, Virginia, 1908.

As World War I approached, aircraft became an essential part of war and peace. In 1907, the US Army renewed its interest in the Wright Brothers. The Board of Ordnance and Fortification and the U.S. Signal Corps announced an advertisement for bids to construct an airplane. [16] However, the design and performance specifications were such that the Wrights were the only viable bidder. A price of $25,000 was set for the brothers' airplane, if they could meet the performance criteria in actual flight trials.

These flight trials were scheduled for late summer 1908 at Fort Myer, Virginia, a military post outside Washington, D.C. With the commitments in Europe, the brothers had to separate for the first time. With Wilbur off to France, Orville did the flying for the Army.

From the source document for the *U.S. Signal Corps Agreement and Specifications for a Heavier-Than-Air Flying Machine* we have Measures of Effectiveness, Measures of Performance, Technical Performance Measures, and Key Performance Parameters.

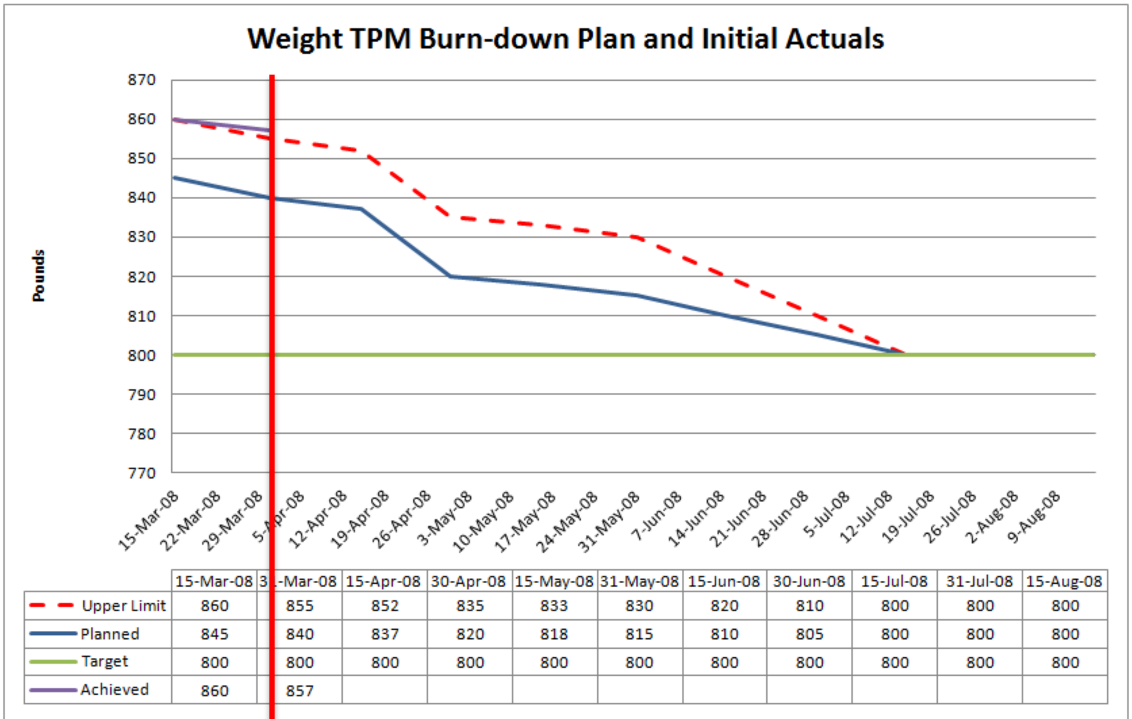
Table 3 – Obtained from historical documents in aviation archives, the Wright brothers needed to address the following Measures of Effectiveness, Measures of Performance, Technical Performance Measures, and Key Performance Parameters in their program.

Historical Document	Program Performance Measure
The flying machine must be designed to carry two people having a combined ***weight of no more than 350 pounds***,	MOP
Also sufficient fuel for a ***flight of 125 miles***	MOP
The flying machine should be designed to have a ***speed of at least 40 miles per hour in still air for at least 125 miles***	MOP
The flying machine should be designed so that it may be ***quickly and easily assembled*** and ***taken apart*** and ***packed into an Army wagon***.	KPP
It should be capable of being ***assembled and put in operating condition within one hour***	KPP
Before acceptance, a ***trial endurance flight*** will be required of ***at least one hour*** during which time,	MOP
The flying machine must ***remain continuously in the air without landing***.	MOE
It shall ***return to the starting point*** and ***land without any damage*** that would ***prevent it immediately starting upon another flight***.	MOE
During this flight of one hour, it ***must be steered in all directions without difficulty*** and at all times ***under perfect control and equilibrium.***	MOE
It should be ***sufficiently simple in its construction*** and ***operation*** to ***permit an intelligent man to become proficient*** in its use within a reasonable length of time.	KPP

The Wright Brothers identified key functions in **Table 3** – Obtained from historical documents in aviation archives, the Wright brothers needed to address the following Measures of Effectiveness, Measures of Performance, Technical Performance Measures, and Key Performance Parameters in their program. to develop a heavier-than-air flying machine. They, and many before them, observed that birds have physical components that enable flight. They needed to develop their own physics components that would enable human flight. [17]

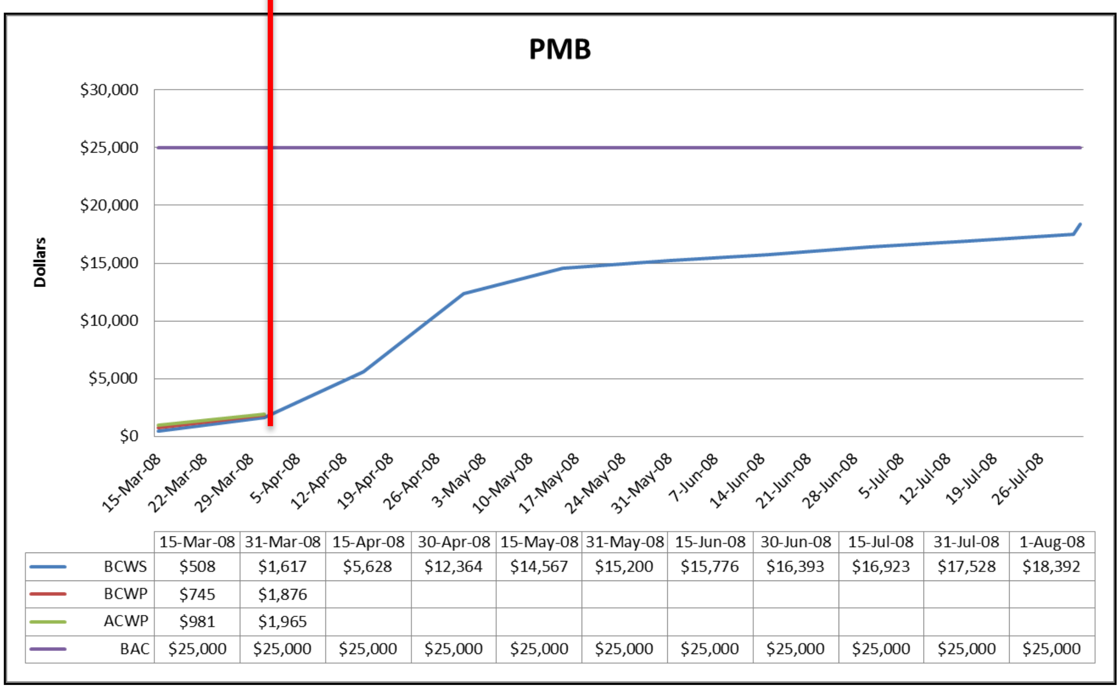
On the train ride from Kitty Hawk back to Dayton Ohio, the Wright brothers decided that, for their aircraft to be a success, their flying machine had to take off in a wide range of weather conditions, navigate to a predetermined location, and "land without wrecking."

Figures 11 and 12 show initial estimated weight against reported EVM data. The actual weight reduction could have been used to drive or inform the cost and schedule status. As the planned weight *burn down* plan occurred, the actual weight reduction was measured. This Technical Performance Measure can be used to inform Earned Value to assess the program performance.



	15-Mar-08	31-Mar-08	15-Apr-08	30-Apr-08	15-May-08	31-May-08	15-Jun-08	30-Jun-08	15-Jul-08	31-Jul-08	15-Aug-08
Upper Limit	860	855	852	835	833	830	820	810	800	800	800
Planned	845	840	837	820	818	815	810	805	800	800	800
Target	800	800	800	800	800	800	800	800	800	800	800
Achieved	860	857									

Figure 11 – The plan to reach an 800-pound aircraft. The actual weight for the first months shows they were above their upper threshold.



	15-Mar-08	31-Mar-08	15-Apr-08	30-Apr-08	15-May-08	31-May-08	15-Jun-08	30-Jun-08	15-Jul-08	31-Jul-08	1-Aug-08
BCWS	$508	$1,617	$5,628	$12,364	$14,567	$15,200	$15,776	$16,393	$16,923	$17,528	$18,392
BCWP	$745	$1,876									
ACWP	$981	$1,965									
BAC	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000

Figure 12 – The Earned Value reported by program controls, showing BCWP not informed by Technical progress.

CONCLUSION

The roadmap to creating a Performance Measurement Baseline (PMB) driven by the system attributes provides meaningful information on program performance to the end user, and how to objectively measure cost and schedule progress based on technical performance. This process starts with a risk-tolerant PMB that adjusts major risks and protects the PMB performance shortfalls from the natural uncertainties that are typically inherent in development efforts.

Calculating and applying schedule margin to accommodate the natural uncertainties and calculation of Management Reserve to account for the unmitigated risks that remain in the risk register is the basis of a credible PMB. Next is the inclusion of Technical Performance Measures, Risk Burn Down, and Schedule Margin Burn Down data used to inform cost and schedule progress.

Creating a credible PMB and keeping the program green to deliver systems that meet the end user needs with a high probability of meeting cost and schedule targets is the goal of integrating the Technical Plan with the Programmatic Plan.

This is done by:

- Having Contractors and Government establish plans and measure integrated technical cost and schedule progress using the principles of Systems Engineering.
- Using the MOE, MOP, KPP, and TPM's originating from the SOW, SOO, ConOps, and other acquisition documents, and assigning these to the IMP and IMS to inform the progress to plan for the program.
- Creating the risk adjusted Technical Plan that is aligned with the Cost and Schedule Plan (PMB).
- Selecting appropriate Technical Performance Measures (TPM) that assess technical progress to plan at the work performance level.
- Establishing the appropriate schedule margin and Management Reserve from the risk adjusted Technical Plan.
- Ensuring cost and schedule performance is consistent with technical performance.

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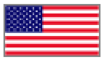

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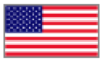

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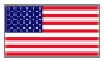

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