Integrating the Embedded Software Path, Model-Based Systems Engineering, MOSA, and Digital Engineering with Program Management February 2, 2025

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Note: This revision refers to the *DOT&E Strategy Implementation Plan* (I-Plan). I-Plan's objectives include:

1. Leveraging digital engineering and implementing efficient digital representations of T&E strategies and plans that trace back to the technical and operational requirements.
2. Effectively using T&E digital twins and the associated verification, validation, and accreditation process.

DoDD 5000.01 The Defense Acquisition System (DAS), includes policies to speed up delivery of products that work as planned, e.g., products that meet the documented capability needs. However, several DoD instructions and guides should be revised to better enable achievement of DAS objectives. Revisions will benefit programs managers (PM) of programs with the following characteristics:

1. Use the embedded software path to develop software embedded in weapon systems.
2. Employ digital engineering (DE) metrics.
3. Employ model-based systems engineering (MBSE).

To speed up delivery of products that work, PMs need timely and accurate schedule status and situational awareness of program execution for proactive resolution of issues impacting cost, schedule, and technical achievement of program objectives. PMs also need situational awareness of the degree of product quality as measured by functional completeness.

Per the DoD DE Strategy (DE Strat), expected benefits of DE include better informed decision-making/greater insight through enhanced transparency and increased efficiency in acquisition practices. This evolution will require engaging contracting and legal teams to streamline business and contracting practices.

DODI 5000.97 DIGITAL ENGINEERING (DE), December 21, 2023:

> DoD will use DE methodologies, technologies, and practices across the life cycle of defense acquisition programs… engineering, and management activities.
> b. As specified in DoDI 5000.88, certain programs must include a DE implementation plan in the SE plan.
> 2.7. DOD COMPONENT HEADS WITH ACQUISITION AUTHORITY.
> (2) Provide guidance and support for program managers (PMs) to develop, validate, and maintain:
> (a) Credible and coherent ASOTs shared with stakeholders.
> (b) Digital models that accurately reflect the architecture, attributes, and behaviors of the system they represent.
>
> 3.2 DIGITAL ENGINEERING CAPABILITY.
> (2) Digital Models (Including Digital Twins).
> (b) …Digital models, including their information and data, should be traceable from operational capabilities through requirements, design constructs, production, test, training, and sustainment….Programs should verify and validate the baseline(s) of digital model(s) before technical milestones.

Pertinent excerpts from DODI 5000.97 are in Appendix D.

DoD Guide - Software Engineering for Continuous Delivery of Warfighting Capability, April 2023 (SWE

Guide):

Excerpts from SWE Guide are in Appendix M.

Defense Science Board (DSB) Reports

The congressionally directed Defense Science Board (DSB) Task Force found that DE, when properly applied, can improve cost, schedule, and performance of complex projects and programs. The Task Force published two reports with recommendations for proper application of DE that are essential to achieve the expected benefits of the DoD DE Strategy.

- DE Capability to Automate Testing and Evaluation–Final Product
- T&E Final Product.

DSB recommendations and qualities include:

- Plan for structured evidence accrual during development and testing to validate performance.
- Incorporate testability requirements in components, subsystems, and systems to speed evidence accrual.
- Develop approaches to report system status.
- Capture data systematically across the life cycle including evidence of cost, schedule, performance.
- The ASOT captures the current state of the technical baseline.
- Once a project commits to DE, its ecosystem must be established, with the appropriate ASOT and all tools necessary to produce artifacts for the user community.

Appendix O includes excerpts from the DSB reports.

Information Needs of Program Managers

However, the current set of instructions and guides focus on engineering, not program management, and are insufficient to enable rapid decisions based on better-informed decision-making/insight of the base measures of schedule and progress. To enhance transparency, the following documents should be revised to address a PM's information needs for authoritative DE metrics of schedule, progress, quality, technical debt, and technical performance. In some cases, the revision should be a referral to SWE Guide:

1. DE Strat
2. DAS
3. DoD Instruction 5000.87 Operation of the Software Acquisition Pathway (5000.87)
4. DoD Instruction 5000.88 DoDI Engineering of Defense Systems (5000.88)
5. DoD Instruction 5000.89 DoDI Test and Evaluation (5000.89)
6. DoD Directive 5000.59 - DoD Modeling and Simulation (M&S) Management
7. DoD Systems Engineering Guidebook (SE Guidebook)
8. DoD SE Plan Outline version 4 (SEP)
9. DoD Integrated Master Plan (IMP) and Integration Master Schedule (IMS) Preparation and Use Guide (IMP/IMS)
10. DoD Integrated Program Management Data and Analysis Report Implementation & Tailoring Guide (IPMDAR Guide)
11. DOD MIL-HDBK-245E, DOD Handbook, Preparation of Statement of Work (SOW Handbook).

The metrics are needed to inform the PM:

1. If the definitions of the technical baselines (functional, allocated, product), and if applicable Minimum Viable Products (MVP), and Minimum Viable Capability Releases (MVCR), will be completed on schedule.
2. If the needed capabilities, features, and functions will be delivered on schedule.
3. If the software engineering processes mitigate cost and schedule risks by identifying and removing software-related technical debt early in development (SE Guidebook).
4. If technical performance is being assessed at all levels: component, subsystem, integrated product, and external interfaces.
5. If the intermediate goals for tracking technical performance measures (TPM) are achieved on schedule.
6. If Modular Open Systems Approach (MOSA), defined interfaces between modules that are defined by widely supported standards are achieved on schedule.
7. If the requirements are validated by testing with a high-fidelity digital twin coupled with high-resolution simulations of the operating environment.

Information Needs of Asst. Sec. of the AF (AT&L)

Mr. Andrew Hunter is Assistant Secretary of the Air Force for Acquisition, Technology and Logistics. In his response to Senate Armed Services Committee (SASC) Advance Policy Questions (APQ) as nominee for that post, on Oct. 5, 2021, he stated that, if confirmed:

> I would also work closely with the Program Executive Officers to ensure all acquisition programs are on track to meet cost, schedule, and performance criteria, and take appropriate actions where needed when this is not the case.
>
> I will perform active and close oversight of the B-21 program….to ensure the B-21 program cost, schedule, and performance stays on track.
>
> I will review the Presidential Aircraft Replacement program in detail…to ensure the program is, and remains, on track to meet cost, schedule, and performance criteria.
>
> I will work with the acquisition workforce leadership to continue emphasizing the pivot to DE and modern software development by leveraging commercial practices and standards.

In his response, he also stated that "I believe that digital acquisition practices such as DE, open systems architecture, and agile software development are best practices in these areas...If confirmed, I will ensure the acquisition community is closely engaged with operators in pursuing technology and continues to employ best practices as we develop capability to meet evolving threats.

The Air Force Material Command (AFMC) released a white paper on Digital Materiel Management (DMM), "DMM: An Accelerated Future State." DMM provides integrated tools built on models, data, and infrastructure to yield radical transparency. With DMM, a program manager can see the status of all deliverables and have instant access to current budget, cost, and program execution data.

Per the AFMC website on Digital Transformation, Digital Transformation is the disruptive enabler the DAF needs to maintain its competitive edge. These digital enablers will allow programs/organizations to:

- streamline operations across ***all functions (not just engineering)***

- increase data access and reliability to enable near ***real-time information***
- drive model-based decision-making with ***authoritative sources***
- enable the redesign and automation of ***cumbersome, manual processes***

Excerpts from the AFMC white paper are in Appendix L.

Information Needs of USD(A&S)

USD (A&S) LaPlante

On March 22, 2022, the Hon. William La Plante appeared before the SASC as nominee for Undersecretary of Defense for Acquisition and Sustainment. In his response to APQs, he stated his positions and commitments regarding EVM, iterative development approaches including MVCs, and DE. Excerpts from the APQ statement follow.

EVM

The earned value management system (EVMS) is used to assess the cost, schedule, and technical performance of major capability acquisitions for proactive course correction. However, the Section 809 Panel reported that EVM does not measure product quality and concluded, "EVM has been required on most large software programs but has not prevented cost, schedule, or performance issues." In 2009 DoD reported to the committee that "a program could perform ahead of schedule and under cost according to EVM metrics but deliver a capability that is unusable by the customer" and stated the program manager should ensure that the EVM process measures the quality and technical maturity of technical work products instead of just the quantity of work performed.

51. If confirmed, what steps would you take, if any, to require contractors to report valid measures of cost, schedule, and technical performance for all acquisition pathways?

If confirmed, I will work across the Department and with the industrial base— current and emerging—to validate, improve, or ***establish appropriate metrics across the acquisition pathways***. … I plan to continue open communications to ensure transparency and allow individual programs to continually improve and tailor approaches to best meet the warfighter need.

52. If confirmed, what steps would you take, if any, to require contractors that employ the DOD DE Strategy to maintain valid information in the digital authoritative data source that is sufficient for program managers to make informed and timely decisions to manage cost, schedule, performance, and risk?

If confirmed, I would seek to engage with our industry partners and Service representatives to better understand how they are currently employing DE and how we can work in partnership to better collaborate within and outside of the Department… A combination of strong data, tool and modeling standards and environments, training of our Acquisition Corps, and proper contract and data rights guidance are foundational to enabling ***successful adoption of DE to feed the right cost, schedule, performance and risk data*** to our acquisition decision makers.

Iterative Development Approaches

40. What is your opinion on the merits of DOD incorporating iterative development approaches centered on fielding minimum viable capabilities?

Best practices in software development focus on rapidly fielding a ***minimum viable capability*** to get into the hands of users to accelerate learning, capture feedback, and use the insights to shape requirements, design, and strategies. … Iterative development can reduce cycle times and be more responsive to changing technologies, operations, and threats. If confirmed, I would seek to promote the DoD's use of this leading industry practice.

41. To what extent do you believe DOD has broadly implemented commercial best practice agile development approaches adequately for software and hardware systems?

… I also understand DoD has taken important steps such as issuing the new Software Acquisition Pathway which is purpose-built to implement best commercial agile approaches and enable modern software practices for ***both applications and embedded software***. DoD is still in the early stages of effectively implementing agile and modern software approaches with progress in software intensive systems that can be leveraged for application to more of our hardware systems. If confirmed, software acquisition will be a high priority.

National Defense Industrial Strategy Implementation Plan (NDIS-IP) for FY 2025

The NDIS-IP includes two Lines of Effort (LOE) tasks that are applicable to EVM. The tasks are develop a study on barriers to entry to the defense industrial base and draft legislation that targets acquisition reform.

LOE 2.1 Task

The OASD (Industrial Base Policy), with support from the Department of Commerce, is developing a study on barriers to entry to the defense industrial base. The study is tasked to identify the major qualification costs and the associated barriers to entry for industry in critical defense sectors and develop policy and qualification standard changes aimed at improving industry collaboration and industrial base production… A successful survey will provide justification for the U.S. government to create legal and policy conditions that facilitate new entrants into defense production and services.

It is recommended that the study determine if the DFARS EVMS clause is a barrier to entry that should be torn down.

LOE 6.3 Task

LOE Task 6.3, Advance the Data, Analytics, and AI Ecosystem, includes the task, "Advance acquisition data analytics." A desired outcome is "support the drafting of legislation that targets acquisition reform."

It is recommended that the acquisition reform legislation include removing the DFARS EVMS clause.

DOT&E Strategy Implementation Plan (I-Plan)

We need to research, pilot, and inform how our future T&E practices leverage digital transformation, DE models, and data collected from across the acquisition life cycle.

We must continue to innovate by enabling more effective digital-physical fusion using live, virtual, constructive training environments; DE and digital twins; and uncertainty quantification.

Leveraging DE and implementing efficient digital representations of T&E strategies and plans that trace back to the technical and operational requirements.

Increasing the use of credible digital twins in T&E by:
(1) developing a methodology to describe the effective use of T&E digital twins and the associated verification, validation, and accreditation process; and
(2) developing and standardizing an architecture for calibrating models based on real, operational data.

Also Needed for Congressional Oversight

The DE metrics should also be sufficient to demonstrate that past and pending DoD commitments to Congress, regarding cost and schedule reporting, will be met. Examples follow.

- **Provision in NDAA for FY 2022 Sec. 1650 Review of EMD Contract for Ground-Based Strategic Deterrent Program (GBSD)**

  Congress is concerned with the implementation of DE as a best practice. The NDAA for FY 2022 includes a provision that specifically addresses the implementation of DE; Sec. 1650, Review of EMD Contract for Ground-Based Strategic Deterrent Program (GBSD). That provision requires a review of DE with concern about the AF's ability to implement DE best practices and to leverage DE. Excerpts follow.

  Excerpts of NDAA provision:

  The Sec. of the AF shall conduct a review…include the following:
  1. An analysis of the ability of the AF to implement industry best practices regarding DE during the EMD phase
  2. An assessment of the opportunities offered by the adoption by the AF of DE processes and of the challenges the AF faces in implementing such industry best practices.
  3. A review of the ability of the AF to leverage DE during such EMD phase.
  4. Recommendations to improve the cost, schedule, and program management of the EMD phase.

  My recommendations for improving the cost, schedule, and program management of the EMD phase and the effectiveness of DE, are covered in Tables 1 and 3 below.

  - Ensure that Integrated Test and Evaluation is integrated with Modeling and Simulation to assess *attainment of technical performance parameters* and to confirm *performance against documented capability needs.*
  - Ensure that programs using the embedded software path align test and integration with the testing and delivery schedules of the overarching system in which the software is embedded, including the testing and delivery schedules of MVPs and MVCRs.

- **2009 DoD Report to Congress Required by WSARA**
  DoD has unfinished acquisition reform tasks to satisfy its commitments in a 2009 report to Congress, *DoD*

EVM: Performance, Oversight & Governance Report. The report was required by WSARA applies to EVM but is relevant to major acquisitions for which reporting of cost and schedule performance is required even if there is no requirement to comply with EIA-748. For easier reading, "EVM" was replaced by "cost and schedule performance" in the following excerpts from the report.

1 SE and cost and schedule performance should be integrated and not stove-piped.

2 The PM should ensure that the cost and schedule performance process measures the quality and technical maturity of technical work products instead of just the quantity of work performed.

3 Cost and schedule performance reporting can be an effective program management tool only if it is integrated with technical performance, if the …processes are augmented with a rigorous SE process, and if the SE products are costed and included in cost and schedule performance tracking.

4 If good TPMs are not used, programs could report (schedule performance) as 100 percent complete even though behind schedule in validating requirements, completing the preliminary design, meeting the weight targets, or delivering software.

- **2014 Report to Congress on Performance Assessments and Root Cause Analyses (PARCA)**

Finally, the PARCA EVM Division will identify, document, and publish specific methods for relating technical performance to earned value performance. *The goal is to provide more accurate joint, program office, and contractor situational awareness of the program execution.* PARCA believes that earned value metrics and technical metrics such as TPMs should be consistent with program progress. Earned Value focuses on the completion of a set of tasks to mature the design. It should be consistent with the set of metrics that indicate the actual design maturity.

- **2018 Section 809 Report**

In 2018, the Section 809 Report of the Advisory Panel on Streamlining and Codifying Acquisition Regulations (Sec. 809 Report) reiterated issues in the DoD reports to Congress. The Panel reported that "another substantial shortcoming of EVM is that it does not measure product quality. A program could perform ahead of schedule and under cost according to EVM metrics but deliver a capability that is unusable by the customer…Traditional measurement using EVM provides less value to a program than an Agile process in which the end user continuously verifies that the product meets the requirement."

- **2022 GAO Report: Congressional Need for Performance Metrics (Cost and Schedule)**

In February 2022, GAO released GAO-22-104687 *DEFENSE ACQUISITIONS Additional Actions Needed to Implement Proposed Improvements to Congressional Reporting.* Per the report, "DOD has yet to decide what information to include in acquisition reports to Congress, including performance metrics for each Adaptive Acquisition Framework pathway … for example, the extent to which a program is meeting its baseline cost and schedule estimates."

- **2022 GAO Report: Leading Practices**

In March 2022, GAO released GAO-22-104513 *LEADING PRACTICES Agency Acquisition Policies Could Better Implement Key Product Development Principles*. GAO found that DOD policies only partially implement a key sub-principle for product development, used by leading commercial companies, to "Use Iterative Design and Testing to Identify a **Minimum Marketable Product**."

GAO reviewed policies for provisions requiring development of a MVP or ***initial capability*** to be improved by subsequent or evolving releases. "GAO found that DOD Directive 5000.01 implies iterative design followed by successive updates, but there is **no reference to a minimum product** prior to developing successive updates. By comparison, the software policy requires program officials to "use an iterative, human-centered design process to define the MVP recognizing that an MVP's definition may evolve as user needs become better understood." The software policy is limited to software efforts using the software pathway and does not include hardware acquisitions or programs using other pathways.

- **2022 DOT&E Report: DOT&E FY 2021 Annual Report, MVP (DOT&E)**
-

In January 2022, DOT&E assessed Block 4 software development on the F-35 program and discussed the MVP. DOT&E stated:

"Although the program designed C2D2 around commercial "agile software" development concepts, it does not adhere to the published best practices that include clear articulation of the capabilities required in the MVP, focused testing, comprehensive characterization of the product, and full delivery of the specified operational capabilities. The program did not deliver programmed capabilities to operational units, as defined in the Air Systems Playbook."

- **Report to Accompany the SASC NDAA for FY 2023, sec. 801, Middle Tier Authority (MTA), with regard to the test plan.**

Modifications to MTA. Sec. 801:

The committee is concerned that the desire for speed in these programs could lead to the omission of key elements of good program management. Therefore, the committee believes that MTA programs and the associated stakeholders would benefit from a … test plan.

- **2022 SE Guidebook:**

2.2.4 Software Engineering

To adopt commercial best practices and advances, Program Management Offices should use the DoDI 5000.87 for software acquisition.

- **2023 GAO Report: DEFENSE SOFTWARE ACQUISITIONS Changes to Requirements, Oversight, and Tools Needed for Weapon Programs**, GAO-23-105867, July 2023

Finding: Existing policies and guidance do not Support DOD oversight of non-software pathway weapon programs using agile. Without the use of outcome-based metrics and continually assessing the value of what was delivered against user needs, a program using Agile software development might deliver capabilities and features that are not essential to the customer and that could contribute to schedule and cost overruns.

Recommendations to Sec. Def:

1: Incorporate Agile principles into requirements policy and guidance for all programs using Agile for software development. This should include a Capability Needs Statement and User Agreement.

2: Incorporate oversight of Agile development of software into acquisition policy and guidance for all programs using Agile. This should include use of metrics, including outcome-based metrics, and continually assessing the value of capability delivered to support iterative software development.

3. Establish an overarching plan—which identifies associated resources—to enable the adoption of modern engineering tools, across all programs. This should include (1) mission engineering, (2) SE, and (3) software engineering.

- **Provision in NDAA for FY 2021 SEC. 836. DIGITAL MODERNIZATION OF ANALYTICAL AND DECISION-SUPPORT PROCESSES FOR MANAGING AND OVERSEEING DEPARTMENT OF DEFENSE ACQUISITION PROGRAMS.**

  Excerpts:

  - Iteratively develop and integrate advanced digital data management and analytics capabilities, consistent with private sector best practices, that—
    - ***integrate*** all aspects of the defense acquisition system, including …***acquisition, management,***
    - enable the use of such data to inform further development***, acquisition, management and oversight of such systems, including portfolio management;*** and
    - include software capabilities to collect, transport, organize, manage, make available, and analyze relevant data throughout the life cycle of defense acquisition programs, including any data needed ***to support individual and portfolio management of acquisition programs.***
  - Supply data to DE models for use in the defense ***acquisition, sustainment, and portfolio management processes;***
  - Move supporting processes and the data associated with such processes from ***analog to digital format, including planning and reporting processes;***

- **CMU/Software Engineering Institute (SEI) SEI-2023-TR-003 | SOFTWARE ENGINEERING INSTITUTE | CARNEGIE MELLON UNIVERSITY, Report to the Congressional Defense Committees on National Defense Authorization Act (NDAA) for Fiscal Year 2022 Section 835 Independent Study on Technical Debt in Software-Intensive Systems, November 2023**

  Excerpts follow:

  • Programs should employ both automated (e.g., static code analysis scans) and manual (e.g., opportunities for developers to add technical debt items to the backlog and tag them as technical debt when intentionally taking on debt or identify technical debt in design reviews) mechanisms for identifying technical debt.

  • Programs should track technical debt items on the backlog separate from other types of items, such as vulnerabilities and defects.

  • Programs should allocate appropriate effort during iteration capacity planning for resolving technical debt items, and they must ensure that this effort is protected from the pressure to focus on new capabilities.

  • Program roadmaps should include the effort for managing technical debt to ensure that it is

planned and that effort is allocated to it over time.

Takeaway: Include technical debt in DoDI 5000.88, Engineering of Defense Systems and the Engineering of Defense Systems Guidebook as shown in Table 3.

- **2024 The DoD PPBE Implementation Plan**

  The Plan includes "Operationalize understanding of best practices within private sector." Guidance to adopt commercial best practices and advances for software acquisition is in the DoD SE Guidebook.
- **2018 DoD Defense Science (DSB) Board Report *Design and Acquisition of Software for Defense Systems* (See Appendix F)**
- **2019 NDIA SE Div. Input to DSB (See Appendix F)**
- **2006 INCOSE International Symposium paper, "Using Earned Value to Track Requirement Progress" July 2006 (INCOSE Track) (See Appendix G)**
- **2024 GAO Report NAVY FRIGATE Unstable Design Has Stalled Construction and Compromised Delivery Schedules GAO-24-106546, May 2024**

  "While the Navy tracks design progress, its process to calculate design stability hinges largely on the ***quantity—rather than the quality***—of completed design documents. ***The focus on quantity obscures functional design progress and how much design work remains.***

- **2024 GAO Report, GAO-24-105503 Navy Shipbuilding Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries, May 2024**

  How programs measured their achievement of design maturity varied but typically reflected **percentages** of design drawings or design-specific contract deliverables expected to be submitted at key milestones before construction. Navy shipbuilders noted that using this type of metric does not necessarily provide a clear understanding of overall design maturity. For example, the metrics may overstate design completeness by giving builders credit for submitting design-related documentation without fully accounting for the quality or completeness of associated design. Drawings that appear complete could include design placeholders that lack necessary vendor-furnished information (VFI) for key equipment and, consequently, mask design uncertainties and remaining design work. Further, Navy officials noted cases where builders submitted blank design products, which met the submittal deadline to the Navy but did not contribute to advancing design maturity.

- **2024 R E P O R T OF THE COMMITTEE ON ARMED SERVICES HOUSE OF REPRESENTATIVES ON H.R. 8070, REPORT 118–529, May 31, 2024**

  DoD Technical Debt

  The committee recognizes that technical debt is a known challenge for the agile acquisition of both software intensive systems and networking hardware infrastructure. … The committee recognizes that addressing technical debt in software is only part of the equation, and technical debt in hardware must also be addressed to be able to effectively use software and new applications like artificial intelligence. Therefore, the committee encourages the Chief Information Officer of the Department of Defense, the Director of the Defense Information Systems Agency, and the Chief Information Officer of each military service to prioritize the reduction of technical debt in software-intensive systems and hardware systems upon which software-intensive systems operate.

- **2024 Report of the Defense Business Board (DBB) Business Transformation Advisory Subcommittee, *Creating a DoD Digital Ecosystem,* DBB FY24-03.**

  The Subcommittee was tasked by the Deputy Secretary of Defense to evaluate the need for lifecycle digitalization and to provide recommendations on creating a digital ecosystem with industry partners.

  Defense Digital Transformation

  The immediate and rapid development of a Defense Digital Ecosystem must become a top national security priority if the United States is to maintain its military advantage over the pacing threat from adversaries, including the People's Republic of China, who are aggressively transforming their defense production processes. In this rapidly evolving threat environment, the establishment of a Defense Digital Ecosystem across weapon system development, acquisition, sustainment, and operations is essential to ensuring the agility and ability to deliver disruptive capability to the warfighter "at the speed of relevancy."

  - DoD must establish new best practices that can be rapidly replicated in a broader transformation. ... recognition that digital transformation will impact a wide array of functions and processes, including but not limited to engineering, tech infrastructure, contracting, sustainment and logistics, budget, legal, and personnel.

  - Ensure sustainment and performance data are connected via digital threads. Progressive efforts must include expertise from all phases of the Acquisition process to account for interrelated processes, data needs, and information flows.

  - Digitalization is not merely turning analog processes into digital (i.e., making paper drawings into digital artifacts), rather it is the breaking down of organizational, process, and production silos using an open digital ecosystem and access to a common set of data.

  - A combination of longstanding bureaucratic inertia; a culture known to be highly risk-averse; workforce gaps; and resource availability present significant barriers to success

  - Changing DoD's prevailing risk-averse culture and inefficient business processes is essential for the success of any enterprise-level digital initiative.

2024 GAO Report GAO-24-106886 Cites Best Project Management Leading Practices in Capability Maturity Model® Integration (CMMI®) Model V3.0

Per GAO Report GAO-24-106886, the ISACA Capability Maturity Model® Integration (CMMI®) Model V3.0 contains the best project management leading practices for the following project management activities; bidirectional requirements traceability, risk management activities, product integration, quantitative performance targets, verification, and validation. Appendix I is a table of the pertinent best project management leading practices. These practices include artifacts that are part of the digital ecosystem.

For additional information, please read the Carnegie Mellon U./Software Engineering Institute Technical Note CMU/SEI-2002-TN-016, Oct. 2002, "Using CMMI® to Improve Earned Value Management." Although written in 2002, it is relevant to today's digital engineering ecosystem. Just skip the obsolete sections regarding EVM.

2024 GAO Report Cites Industry Leading Practices Such as Digital Twins (Digital Twin)

GAO-24-106792, *HYPERSONIC WEAPONS DOD Could Reduce Cost and Schedule Risks by Following Leading Practices*, cites the industry leading practice of developing a variety of models using digital engineering tools, such as digital twinning, during the design modeling and simulation phase. A high-fidelity digital twin, coupled with high-resolution simulations of the operating environment, can be used for testing the system to validate that it meets requirements. This reduces the need to build physical prototypes each time the design changes. In addition, digital twins are also useful in the sustainment phase. These digital design tools are useful in the design and validation process as they can enable more rapid iterative design cycles and facilitate stakeholder and user feedback at earlier stages.

Note:
Commercially available tools are available that enable the use of a digital twin to:

1. Track execution status of validation and verification activities.
2. Perform verification management and build a product that works, faster and more efficiently.

Excerpts from

Appendix J includes excerpts from one vendor's solution to "prepare to transform your product development process with verification management solutions leveraging a digital twin."

2024 SASC Report for NDAA for FY 2025

The SASC Senate Report 118-188**,** *NDAA for FY 2025 [to accompany S. 4638],* Updates to EVMS requirements (sec. 823), July 8, 2024, confirms that EVM is limited to work scope and has limited value to "smaller projects." The Report also "recognizes the burden it places on small businesses and non-traditional defense contractors that must make significant internal investments to create a compliant EVM system."

The Report cites "the ***rigor*** this tool brings to contracts for major hardware systems" but is silent on whether EVM provides any management ***value*** to those systems.

The Report's focus on EVM's ***work scope*** and silence on ***product scope*** indicates that the SASC is cognizant of the shortcomings of EIA-748. Compliance with EIA-748 does nothing to support the DAS "Performance-based strategy" for an acquisition approach structured around ***the results to be achieved*** as opposed to the manner by which the ***work is to be performed*** (Table 1)**.**

2024 GAO Report on Minimum Viable Product (MVP), Digital Engineering, Digital Twins, Digital Threads, and Validating Hardware and Software

This white paper already recommended that DOD revise acquisition policies and guides to address the Minimum Viable Product **(**MVP). The new GAO report acknowledges that DOD is revising some of its acquisition policies. However, GAO also recommendation that the Air Force, Army, and Navy revise their acquisition policies and relevant guidance to reflect leading practices that facilitate the development of a MVP (GAO-25-107003 DOD ACQUISITION REFORM Military Departments Should Take Steps to Facilitate Speed and Innovation, December 2024).

The GAO report also states that the iterative structure is enabled by digital engineering, such as digital twins or digital threads. Digital twins are virtual representations of physical products and incorporate dynamic data of a physical object or system meaning the model changes and updates in real-time as new information becomes available. Digital threads are a common source of information that connect stakeholders with real-

time data across the product life cycle. The number of cycles a product requires can vary, but programs would use multiple iterations to ensure all hardware and software needs are validated through testing and user feedback.

NDAA for FY 2025, SEC. 804. MIDDLE TIER OF ACQUISITION FOR RAPID PROTOTYPING AND RAPID FIELDING

The provision in the pending NDAA for FY 2025, SEC. 804. MIDDLE TIER OF ACQUISITION FOR RAPID PROTOTYPING AND RAPID FIELDING, to "seek an expedited waiver from any regulatory requirement, or in the case of a statutory requirement, a waiver from Congress, that the program manager determines adds cost, schedule, or performance delays with little or no value to the management of such program or project." The white papers, Common Sense Project Management: "When *you* come to a fork in the road…," 11/26/24, and Outcome-based Metrics Plus SE = Integrated Program Management, Rev. 9, provide independent assessments, justifications, and evidence that a program manager should use when seeking the waiver from the DFARS Earned Value Management System (EVMS) clause because implementation of the EVMS standard, EIA-748, adds cost and schedule delays with no value to the management of a program.

This white paper provides guidance to use in preparing the request for the waiver. The program manager should commit to obtain timely and accurate schedule status and situational awareness of program execution for proactive resolution of issues impacting cost, schedule, and technical achievement of program objectives. The guidance and examples herein, especially regarding DE, ASoTs, and Common Sense Project Management will provide "Something of Value" to replace earned value.

Recap of Reports

The Sec. 809 Report's assessment indicates that DoD's EVM commitments to Congress in 2009 and 2014 have not been met. PARCA's goal of *accurate joint, program office, and contractor situational awareness of the program execution* is relevant to development programs, including those with no EVM requirements, but that goal is unmet. There is a need to integrate DE with program management. For successful implementation of the DE Strat and to meet DAS goals, additional guidance is needed to ensure that the *PM measures schedule and progress towards meeting the requirements of the technical baseline.*

Recommendations

Recommendations are provided herein that define the PM's information needs and the DE metrics that meet those needs. Authoritative Sources of Truth (ASOT) for selecting DE metrics and recommended DE artifacts/work products that may be used as base measures of DE metrics are included in Appendices A and B.

The pertinent overarching DAS policies and objectives are:

1. Deliver Performance at the Speed of Relevance using *data driven* analysis.
2. Employ Performance Based-Acquisition Strategies that are structured around *the results to be achieved as opposed to the manner by which the work is to be performed*.
3. Conduct Integrated Test and Evaluation (T&E), *integrated with (M and S),* to assess *attainment of technical performance parameters* and to confirm *performance against documented capability needs.*

The five documents cited above can be improved to better define the information needs of PMs for effective program technical planning and management, configuration and change management, and software

engineering.

The PM needs accurate schedule status and situational awareness of program execution for proactive resolution of issues impacting cost, schedule, and technical achievement of program objectives. The technical achievement criteria are defined in the technical baselines. The PM also needs situational awareness of the degree of product quality as measured by functional completeness.

Finally, the exchange of schedule status information via model exchanges and automated transformations will eliminate the manual entry of estimated schedule performance such as the percent of work complete used with EVM. The estimated percent of work complete, such as drawings or code, may fail to be an indicator of the true status of validating requirements, completing the preliminary design, meeting the weight targets, or delivering software and may fail to properly account for rework.

Per GAO-24-105503 Navy Shipbuilding Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries, May 2024, several Navy shipbuilding programs set thresholds for the degree of design maturity that reflected percentages of design drawings expected to be submitted at key milestones. However, Navy shipbuilders noted that using this type of metric does not necessarily provide a clear understanding of overall design maturity. For example, the metrics may overstate design completeness by giving builders credit for submitting design-related documentation without fully accounting for the quality or completeness of associated design. Drawings that appear complete could include design placeholders that lack necessary VFI for key equipment and, consequently, mask design uncertainties and remaining design work.

Common DE Specifications and Standards for Model Exchanges and Automated Transformations

DoD recently established the new position of Chief Digital and Artificial Intelligence Officer (CDAO). The CDAO should be responsible for addressing the DE Strategy statement that "DoD will need to encourage commonality in terminology, develop a shared understanding of concepts, and ensure consistency and rigor in implementing DE across engineering activities…by evaluating current policy, guidance, specifications, and standards to determine what changes are necessary to implement DE."

The evaluation should include providing a specifications and standards for exchanging data between the engineering requirements management data base (such as DOORS), the ASOT, and the program cost and schedule reports such the Integrated Program Management Data and Analysis Report (IMPDAR). The IMPDAR's components include the Contract Performance Dataset (CPD) which provides performance/execution data from the contractor's existing management systems and the schedule (comprised of both the Native Schedule File and the Schedule Performance Dataset (SPD) which provides data from the contractor's Integrated Master Schedule.

The Practical Software and Systems Measurement (PSM) DE Measurement Framework Version 1.1, published by the DoD Digital Engineering Working Group (DEWG), provides guidance to use Model-Based Systems Engineering (MBSE) practice to:

1. Fully integrate system data and models with engineering, ***program management***, and other domains and disciplines.
2. Collect data directly from DE modeling tools and record results in team tracking tools, such as the schedule.

Pertinent excerpts from PSM are in Appendix H.

The schedule and technical performance data collected from DE modeling tools is recorded in the schedule without manual intervention, manipulation, or elimination, as compared with earned value, thus preserving its truth and management value.

DoD Directive 5000.59 - *DoD Modeling and Simulation Management* should be revised to assign responsibility to the CDAO for developing specifications and standards. Of course, budget should be requested to develop the specifications and standards.

Action Plan

It is recommended that the documents cited above be revised, as specified in Table 3. It is also recommended that the DEWG develop and publish metrics specifications for DE and MBSE that support the information needs of PMs. The metrics specifications should be used as digital ASOTs for three PM responsibilities.

1. Develop the time phased schedule to complete the requirements definitions. It should reside in an automatedly linked scheduling system.
2. Assess the schedule progress of defining and completing requirements. Schedule progress should also reside in an automatedly linked scheduling system.
3. Use digital artifacts from the ASOT as base measures of DE metrics. These digital artifacts are ASOT that SE work products are completed, such as:
   - Requirement definitions including approved technical performance measures (TPM), verification methods, and completion criteria in the functional and allocated baselines.
   - Trade studies
   - Completed products in the product baseline including the MVP and MVCR baselines, if applicable
   - Test artifacts (e.g., test cases, plans, deficiencies, and results)

With MBSE, the record of authority shifts away from the documents to the digital model. Digital modeling provides an analytical tool, a coverage metric, to evaluate a current state of the model. In addition to calculating statistics of how many requirements are covered by test cases (Verify relationship) or design elements (Satisfy relationship), every metric records a time stamp. Periodically calculating the same metric allows the user to monitor changes of a specific aspect of the model in time.

The EVMS DFARS clause should be revoked. It is an impediment to achieving DBB's objectives such as:

- Use digital threads to account for interrelated processes, data needs, and information flows (regarding measuring schedule, technical and cost performance based on ASoTs).
- Break down organizational, process and production silos using an open digital ecosystem and access to a common set of data.
- Overcome bureaucratic inertia and risk-adverse culture…significant barriers to success (in holding program managers and contractors accountable for program failures).
- Changing DoD's prevailing inefficient business processes (for measuring cost, schedule, and technical performance and for providing early warning of pending failures) for the success of any enterprise-level digital initiative.

However, until the EVMS DFARS clause is invoked, reported earned value should be based on the status of the requirements and technical maturity of the product being developed, not the quantity of work performed. For example, when using Agile methods, earned value could be based on the percent of requirements or user stories completed in the release burnup in the next MVP. See Appendix I, **Artifacts, Milestones, and Metrics to**

Use for Embedded Software When EVMS is Required.

Source Table 3:

The pertinent DAS overarching policies and objectives are ASOTs for the purposes of the recommendations herein. They are in Table 1.

Table 1 ASOT for DE Metrics Specifications	
DAS Section	**Excerpts**
1.2.a	**Deliver Performance at the Speed of Relevance.** The DAS will: (d) Conduct ***data driven*** analysis.
1.2.k	**Employ Performance Based-Acquisition Strategies** To maximize competition, innovation, and interoperability, acquisition managers will consider and employ performance-based strategies for acquiring and sustaining products and services. "Performance-based strategy" means a strategy that supports an acquisition approach structured around ***the results to be achieved as opposed to the manner by which the work is to be performed*.**
1.2.o	**Conduct Integrated Test and Evaluation** (T&E) (1) T&E will be integrated throughout the defense acquisition process. Test and evaluation will be structured to provide essential information to decision makers, assess ***attainment of technical performance parameters***, and determine whether systems are operationally effective, suitable, survivable, and safe for intended use. (2) The conduct of T&E, ***integrated with M&S*** will: (b) *Assess* ***technology maturity*** and interoperability. (d) Confirm ***performance against documented capability needs*** and adversary capabilities.

The recommended document modifications herein pertain to the following Information categories and measurable concepts in *PSM*. See Table 2 and Appendix C.

Table 2 PSM Information Categories and Measurable Concepts	
Information Category	**Measurable Concept**
Schedule and Progress	Work Unit Progress, Deployment Lead Time (a) (a) Deployment Lead Time is a measure of how rapidly authorized requests for system capabilities and work products can be engineered, developed, and delivered for use in their intended operational environment.
Product Quality	Functional Completeness (Traceability)

The proposed metrics specifications and DE artifacts support the objectives of and are consistent with documents that, in my opinion, are ASOT for DE. The documents follow.

- DoDI Instruction (DoDI) 5000.61 DOD MODELING AND SIMULATION VERIFICATION, VALIDATION, AND ACCREDITATION, September 17, 2024
- DoDI 5000.80, Middle Tier of Acquisition
- DoDI 5000.85, Major Capability Acquisition

- DoDI 5000.87, Software Acquisition
- DoDI 5000.88, Engineering of Defense Systems
- DoDI 5000.89, Test and Evaluation
- DoDI 5000.97 DIGITAL ENGINEERING (DE)
- DoD DE Strat
- DoD Software Modernization Strategy (SW Modernization)
- DoD Best Practices for Using SE Standards (ISO/IEC/IEEE 15288, IEEE 15288.1, and IEEE 15288.2) on Contracts for DOD Acquisition Programs (15288BP)
- SEI Blog Posts by Natalia Shevchenko Requirements in MBSE, Feb. 22, 2021Benefits and Challenges of MBSE, July 2021
- DoD SE Plan Outline version 4 (SEP)
- DoD Risk, Issue, and Opportunity (RIO) Management Guide for Defense Acquisition Programs, 2023
- DOT&E
- DoD IMP/IMS
- Engineering of Defense Systems Guidebook
- DoD Software Engineering (SWE Guide)
- GAO-20-590G *GAO Agile Assessment Guide* (GAO Agile)
- GAO Schedule Assessment Guide (GAO Schedule)
- Defense Business Board Business Transformation Advisory Subcommittee report, *Creating a DoD Digital Ecosystem*
- National Science Foundation Research Infrastructure Guide (NSF)
- NDIA Integrated Program Management Division, A Guide to Managing Programs Using Predictive Measures, March 26, 2021 Rev. 3 (Predictive Measures).
- PSM DE measurement framework
- SE Guidebook
- International Counsil on SE (INCOSE) SE Leading Indicators Guide (SELI)
- Solomon, Paul. INCOSE International Symposium paper, “Using Earned Value to Track Requirement Progress” July 2006 (INCOSE Track)
- SERC SE Research Center Task Order WRT-1001: Digital Engineering Metrics, Technical Report SERC- 2020-TR-002 (SERC)
- Solomon, Paul. SEI Technical Note CMU/SEI-2002-TN-016, Oct. 2002 "Using CMMI® to Improve EVM” (SEI-EVM)
  Note: Despite its title, EVM is applicable to any project including projects that do not use EVM. SEI focuses on the base measures of work unit progress.
- Solomon, Paul and Young, Ralph. Performance-Based Earned Value, IEEE Computer Society/John Wiley and Sons, 2007. (PB-EV)
- 2018 DoD Defense Science (DSB) Board Report *Design and Acquisition of Software for Defense*

Systems (See Appendix F)

- 2019 NDIA SE Div. Input to DSB (See Appendix F)
- DoD *Agile Metrics Guide Strategy Considerations and Sample Metrics for Agile Development Solutions* Version 1.2, 11 November 2020 (*Agile Metrics*)
- *PSM*
- GAO-24-106792

Recommended revisions to DAS, DoDI 5000.80, DODI 5000.87, DODI 5000.88, DODI 5000.89, DE Strat, SEP, and IPMDAR Guide are included Table 3.

Table 3 Recommended Revisions to Authoritative Sources of Truth for Embedded Software and DE Metrics Specifications

Doc.	Excerpts	Revision
DAS DoDD 5000.01	g. Employ a Disciplined Approach. (2) Program goals for cost, schedule, and performance parameters (or alternative quantitative management controls) will describe the program over its life cycle. Approved program baseline parameters will serve as control objectives.	objectives Insert: technical Add: including, the product baseline and, if appropriate, the MVP and MVCR baselines.
DoDI 5000.80	f. CAEs will ensure that MTA program names and budget reporting clearly and discretely indicate the scope of the effort being conducted under the MTA pathway, especially when the MTA program is a subprogram of a larger program or is a program spiral, increment, or block upgrade. USD(A&S) will maintain the authoritative list of MTA programs for the Department.	Department Add: Scope includes functional, allocated, and product baseline. (See DoDI 5000.88)
DoDI 5000.87	3.2 f. Test Strategy. (1) The test strategy defines the streamlined processes by which capabilities, features, user stories, use cases, etc., will be tested and evaluated to satisfy developmental test and evaluation criteria and to	embedded Insert: including the testing and delivery
	demonstrate operational effectiveness, suitability, interoperability, and survivability, including cyber survivability for operational test and evaluation. The strategy will: (f) Programs using the embedded software path will align test and integration with the testing and delivery schedules of the overarching system in which the software is embedded, including aligning resources and criteria for transitioning from development to test and operational environments.	schedules of MVPs and MVCRs.

DoDI 5000.87	3b(11) Each program will develop and track a set of metrics to assess and manage the performance, progress, speed, cybersecurity, and quality of the software development, its development teams, and ability to meet users' needs. Metrics collection will leverage automated tools to the maximum extent practicable. The program will continue to update its cost estimates and cost and software data reporting from the planning phase throughout the execution phase.	performance Insert: technical collection Add: , including collection of DE metrics of schedule progress towards the MVP and MVCR.
DoDI 5000.88	**3.4 b. Technical Baseline Management** The PM will implement and describe in the SEP a ***technical baseline*** management process as a mechanism to manage ***technical maturity***, to include a mission, concept, ***functional, allocated, and product baseline.*** If practicable, the PM will establish and manage the technical baseline as a digital ASOT.	product baseline, Add: including, if needed, MVP and MVCR baselines.
DoDI 5000.88	**3.4. PROGRAM TECHNICAL PLANNING AND MANAGEMENT**. a. SEP (3) For MDAPs, ACAT II, and ACAT III programs, the SEP will contain these elements, unless waived by the SEP approval authority:	Add: (u) DE metrics of schedule progress will be ASOT for tracking and reporting metrics for technical performance, schedule progress, and quality.
DoDI 5000.88	**3.4. PROGRAM TECHNICAL PLANNING AND MANAGEMENT**. a. SEP (3) For MDAPs, ACAT II, and ACAT III programs, the SEP will contain these elements, unless waived by the SEP approval authority: (b) The engineering management approach to include ***technical baseline management; requirements traceability; CM***; risk, issue, and opportunity management; and technical trades and evaluation criteria.	traceability; Including automated traceability to completion criteria in the schedule,
DoDI 5000.88	**3.4. PROGRAM TECHNICAL PLANNING AND MANAGEMENT**. a. SEP (3) For MDAPs, ACAT II, and ACAT III programs, the SEP will contain these elements, unless waived by the SEP approval authority: (c) The software development approach to include architecture design considerations; software unique risks; software obsolescence; inclusion of	**progress,** Should be: ***schedule progress,***
	software in technical reviews; ***identification, tracking, and reporting of metrics for software technical performance,*** process, progress, and quality; software system safety and security considerations; and software development resources.	

DoDI 5000.88	**3.4. PROGRAM TECHNICAL PLANNING AND MANAGEMENT**. a. SEP (3) For MDAPs, ACAT II, and ACAT III programs, the SEP will contain these elements, unless waived by the SEP approval authority: (r) The MOSA and program interdependencies with other programs and components, to include standardized interfaces and schedule dependencies.	Interfaces and schedule dependencies. Delete: "and" Add: , schedule dependencies, and collection of DE metrics of schedule progress towards developing and verifying the MOSA interdependencies and standardized interfaces.
DoDI 5000.88	3.4.c. Configuration and Change Management The LSE, under the direction of the PM, will implement a digital CM approach and automated tools to establish, control, and curate product attributes and technical baselines across the total system life-cycle. The CM approach will: (1) Identify, document, audit, and control schedule, cost, functional, physical, and performance characteristics of the system design. (2) Specifically, track any changes (e.g., a dynamic change log for in and out of scope changes, formal engineering change proposals) and provide an audit trail of program design decisions and design modifications. (3) Provide for traceability of mission capability to system requirements to performance and execution metrics.	performance Insert: technical performance Insert: technical metrics, Add: including DE metrics for schedule progress and quality
DoDI 5000.88	3.6 Specialty Engineering 3.6.a(2)(a)6 Metrics identification, tracking, and reporting to address software ***technical performance***, development process, and quality.	technical performance, Insert: schedule progress,
DoDI 5000.88	3.6 Specialty Engineering 3.6.a(2)(a)	Insert: 9 technical debt
DoDI 5000.88	3.6.a(2)(b) The program may automate collection of metrics as much as possible.	metrics Insert: , including DE metrics for schedule progress and quality,
DoDI 5000.89	3.1.i As part of the DE strategy… tools...must provide authoritative sources of models, data, and test artifacts (e.g. test cases, plans, deficiencies, and results)	results Insert: , including DE metrics for schedule progress and quality,

DoDI 5000.97	3.2.b(4)(j) Test planning and cases	Is: Test planning and cases Should be: Test planning, cases, and testability requirements
DoDI IMP/IMS	2.2.4 Software Acquisition Although an IMS typically would not include Level of Effort (LOE) activities, the program should schedule MVP and post MVCR sprints in the IMS. Programs should work closely with their software development team to ensure the IMP structure matches the structure of Agile elements. For example, features or capabilities from an Agile perspective often correlate to the Criteria level of a project's IMP.	In the IMS Insert: "as IMP events" Also, delete "Although an IMS typically would not include Level of Effort (LOE) activities." It is irrelevant to embedded software.
DE Strat	1.3 Exchange of information between technical disciplines or organizations should take place via model exchanges and automated transformations.	information Insert:

		, including DE metrics for schedule progress and quality,
DE Strat	**2.3 Use the digital ASOT as the technical baseline** Stakeholders should use the ASOT to make informed and timely decisions to ***manage cost, schedule, performance, and risk***. For example, contract deliverables should be traced and validated from the ASOT**.**	performance Insert: technical deliverables Insert: that report schedule progress and product quality (functional completeness)
IPMDAR Guide	1.2. IPMDAR consists of the following three components: … The IPMDAR requirement is comprised of three components: the Contract Performance Dataset (CPD), the Schedule (to include Native Schedule and Schedule Performance Dataset (SPD),	1.2. IPMDAR consists of the following four components: The IPMDAR …The IPMDAR requirement is comprised of four components: and the DE artifacts that are created from the standards, rules, tools, and infrastructure within a DE ecosystem, including schedules.
IPMDAR Guide	1.2.2 Schedule (Comprised of both the Native Schedule File and the Schedule Performance Dataset (SPD)). Provides data from the contractor's Integrated Master Schedule (IMS). The Native Schedule submission is a direct export from the contractor's scheduling tool. The SPD is a collection of JSON encoded data tables capturing the detailed task and schedule metrics, task relationships, and resource assignments tables. Since the CPD data report is now required at the CA or WP levels, the task definitions within the SPD must now be correctly encoded against the CA or WP data included in the corresponding CPD submission. This critical improvement enhances the ability to support integrated cost/schedule analysis.	Add For software that is embedded in weapon systems, the contractor's IMS includes milestones and schedule performance from the DE artifacts that are created from the standards, rules, tools, and infrastructure within a DE ecosystem.
IPMDAR Guide	1.3 IPMDAR Outline. 1.3.2 Data reported shall reflect the output of the contractor's Earned Value Management System (EVMS)	Add: and the DE artifacts that are created from the standards, rules, tools, and infrastructure within a DE ecosystem.

IPMDAR Guide	3.4. Applying the IPMDAR DID When EVMS DFARS Clause is not Applicable The Government may apply the Schedule (comprised of both the Native Schedule File and/or the Schedule Performance Dataset (SPD)) deliverable of the IPMDAR DID when the DFARS 234.252-7002 EVM requirement is not on contract. The Schedule is applied to all development, major modification, and low rate initial production efforts.	Add: or when the DFARS 234.252-7002 EVM requirement is not on the software that is embedded in a weapon systems contract.
SEP	3.2.2 TPMs A set of TPMs covering a broad range of core categories, rationale for tracking, **intermediate goals,** and the plan to achieve them with as-of dates.	categories, Insert (from Risk): at all levels including component, subsystem, integrated product, external interfaces.
SEP	3.2.2 TPMs (2) empirically forecast the impact on program cost, schedule, and performance	performance Insert: technical
SEP	3.2.2 **Expectation** Program should use measures	Measures Insert: technical
SEP	**3.2.9 Config. and Change Management** **Technical Baseline Artifacts** – …At a minimum, describe the artifacts of the concept, functional, allocated, and product baselines and when each technical baseline has been or will be established and verified. If practicable, the PM will establish and manage the technical baseline as a digital authoritative source of truth. (*See* SE Guidebook (forthcoming) Configuration Management Process, for additional guidance)	Verified Add: ***The product baseline includes the sequential set of MVP/MVCR baselines as appropriate.*** forthcoming delete
SE Guide-book	2.5 Another area to which incentives are tied…work products	Add: Reduction of technical debt in software-intensive systems and hardware systems upon which software-intensive systems operate.
SE Guide-book	2.5 Another area to which incentives are tied is the EVMS. The PM should ensure that the EVMS, tied to any incentive, measures the quality and technical maturity of technical work products instead of just the quantity of work.	Replace "the EVMS. The PM should ensure that the EVMS, tied to any incentive, measures the quality and technical maturity of technical work products instead of just the quantity of work" with "a set of metrics to assess

		and manage technical performance, schedule progress, speed, cybersecurity, and quality of the development, its development teams, and ability to meet users' needs. Metrics collection will leverage automated tools to the maximum extent practicable. Those metrics will be used to update cost estimates and cost and software data reporting from the planning phase throughout the execution phase. Metrics should address software technical performance and quality (e.g., defects, rework) evaluating the software's ability to meet user needs." (Source: DoDI 5000.87).
SOW Hand-book	APPENDIX A WORK WORDS/PRODUCT WORDS Product Scope (the features and functions that characterize a product, service, or result)	Add: Also called Product Baseline

NDIA Predictive Measures

The NDIA *Predictive Measures* includes predictive indicators that can be used to develop and implement effective mitigation plans. Excerpts from the Sections, Requirements Completion Metrics and Technical Performance Measures (TPM), follow.

NDIA Requirements Completion Metrics

Predictive Nature: Unfavorable differences in requirements completion metrics indicate a threat to timely delivery of a capable system that satisfy stakeholders' needs. The metric indicates progress in eliciting and documenting all the requirements necessary for a final, completed systems design.

The base measures are:

- Total Requirements consisting of:
    1. The physical count of system level requirements statements at the transition from the systems requirements phase to preliminary design.

2. The expected count of requirements analyzed from the system level to be eventually allocated to the system elements (configuration items).

- Requirements Planned - the time-phased profile count of total requirements fully articulated given resource capability and capacity. This value might come from Control Account Plans for completion of specifications.
- Requirements Completed – the count of completed requirements as determined from work package level status reports or system requirements data base.

The basic algorithms are:

$$Planned\ \%\ Complete = \frac{Requirements\ Planned}{Total\ Requirements}$$

$$Actual\ \%\ Complete = \frac{Requirements\ Completed}{Total\ Requirements}$$

NDIA TPM

TPM involves predicting the future values 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. A good TPM has the element of traceability of the technical requirements to WBS to TPMs to EVM Control Accounts. In the Control Account, a description of the TPM and its allowed range of values for the Period of Performance of that Control Account should be defined.

The Systems Engineering Management Plan (SEMP) and the resulting SE architectural documents are used to further define the TPMs and to set threshold values.

Digital Artifacts

Typical artifacts that should be the base measures of schedule performance are outputs from the measurement and verification processes in *OSD Best Practices for Using SE Standards (ISO (International Standards Organization/IEC (International Electrotechnical Commission)/IEEE (Institute of Electrical and Electronics Engineers) 15288, IEEE 15288.1, and IEEE 15288.2) on Contracts for DOD Acquisition Programs* (15288BP), *GAO Agile, PB-EV,* and *CMMI® for Development*, Version 1.3 (CMMI-DEV, V1.3), and DoDI 5000.61. Excerpts from DoDI 5000.61 are in Appendix K.

These outputs are ASOTs for PMs. When DE is employed, the digital versions of these artifacts should be automatically transferred from the engineering to the program management organizations.

Per SE Guidebook, “software development activities should employ automation across all aspects of the software factory and project management components to eliminate tedious, manual steps to the maximum degree practicable, enabling higher velocity, consistency, and overall better-quality software components.

Typical DE artifacts are included in Appendices A and B. The primary source of the artifacts in PB-EV is

the technical note, SEI-EVM. In 2010, SEI published information regarding Agile methods in CMMI-DEV, V1.3. Excerpts from CMMI-DEV, V1.3, including the processes, Requirements Development, Configuration Management, and Quantitative Project Management, are in Appendix E.

Leveraging Commercial Practices and Standards

The Project Management Institute (PMI) *Project Management Body of Knowledge-Seventh Edition* (PMBOK®) provides useful guidance to support AF Asst. Sec. Hunter's commitment to lever commercial practices and standards. It provides Common Sense Project Management guidance to measure quality using metrics and acceptance criteria based on requirements.

A PM's needs that are covered by PMBOK® include artifacts, measures of performance, metrics, Minimum Viable Product, quality, quality metrics, product (including product breakdown structure, product scope), requirements (including requirements baseline, requirements management plan, and requirements traceability matrix), rework, risk (including management plan, risk responses), and technical performance measures. Appendix N includes pertinent excerpts.

The topics in Appendix N, except technical performance measures, are absent from EIA-748. Consequently, a program manager who seeks an expedited waiver from the DFARS EVMS clause may commit to use PMBOK® guidance as a tool for integrated project or program management in conjunction with other elements of this white paper. PMBOK® is product-oriented and requirements-oriented compared with EIA-748's narrow focus on the quantity of work performed.

Appendix A ASOT for Selecting DE Metrics and Typical DE Artifacts

ASOT for Selecting DE Metrics and Typical DE Artifacts	
Doc.	**Excerpts**
5000.61	(1) Descriptions of the V&V activities and results. (2) Summary of results, including the capabilities, limitations, risks, potential impacts to the specific intended use, and assumptions of the model, simulation, distributed simulation, and associated data undergoing V&V.
5000.89	As part of the DE strategy...tools...must provide authoritative sources of models, data, and test artifacts (e.g. test cases, plans, deficiencies, and results)
5000.97	3.5.a(4) Programs will ensure digital models, simulations, and associated data are verified, validated, and accredited for their intended use, in accordance with DoDI 5000.61.
15288BP	6.3.5.4 **Requirements Traceability Mapping** 1) Includes full bi-directional traceability between the requirements source and the system requirements ***down to their lowest level***.
15288BP	6.3.7.4 **Measurement process outputs** c) Measurement data with the following attributes: 1) Provides data on established TPMs for use in project assessment and control to support the assessment of the system technical performance, and for an assessment of risk in achieving the measures of effectiveness or measures of performance and associated operational requirements. NOTE—***TPM***s are a subset of measures that evaluate technical progress (i.e., ***product maturity***) and support evidence-based decisions at key decision points such as technical reviews or milestone decisions. 2) Provides technical project measurement data for use in project assessment and control to support the assessment of ***technical progress toward fulfilling system requirements***.
15288BP	6.4.9.4 ***Verification*** process outputs a) Planned system verification with the following attributes: 1) Quantitatively verifies that ***each system product*** …meets all of its requirements and design constraints in accordance with the ***verification method*** for each requirement or constraint in the allocated baseline. b) Verification results with the following attributes: 1) Verify required ***performance*** of all critical characteristics by demonstration or ***test***. 2) Verify ***risks*** identified in the Risk Management process are ***mitigated*** to levels acceptable for continued development of the system as planned. d) Acceptance verification data with the following attributes: 1) Verifies that each delivered hardware product, each constituent product of a delivered hardware product, and each system product that is used to manufacture, verify, integrate, or deploy end products that are to be delivered meets each of its requirements …in the maintained, allocated, or ***product baselines*** in accordance with the applicable *verification method* or verification requirements.

15288BP	6.4.11.4 ***Validation*** process outputs a) Planned system validation with the following attributes: 2) Identifies any computers and other resources needed for such efforts as well as any needed government-furnished equipment (GFE) and government-furnished information (GFI). 3) Documents a plan for realistically emulating the operational system (e.g., modeling, simulation, prototypes), including human-in-the-loop behaviors, that includes: ii) A representation of all physical devices that have been identified thus far in the synthesis step of the systems engineering processes. 6) Defines in detail and documents the validation process to help ensure that the system meets stakeholder expectations. b) System validation data with the following attributes: 1) Confirms that the system (hardware and software) as delivered satisfies the user's needs and requirements in the intended environments. 2) Confirms that the system fulfills the required functions and has no unplanned detrimental effects in an operational environment. 3) Documents any discrepancies between the i) Product baseline and stakeholder expectations. ii) Specified performance and the performance obtainable by the physical devices selected for the system or its components. iii) The end-to-end test characteristics and mission characteristics. 4) Includes inputs to operational suitability certifications based on program objectives and assessment of progress toward defined certification criteria. 7) Includes end-to-end test results, discrepancies, and exceptions.
SWE Guide	See Appendix M
GAO Agile	**Data from Agile artifacts enables contract oversight** Programs should also collect actual data associated with the program's releases, features, and capabilities to enable contract oversight and hold contractors accountable for producing quality deliverables.
GAO Schedule	**Best Practice 1: Capturing All Activities** Is the IMS maintained in scheduling software and linked to external, detailed project schedules? Risk mitigation activities with scope and assigned resources should appear as discrete activities in the schedule.
NSF	The project management controls should identify the methods and quantitative measures to compare the technical progress and costs during execution to the planned schedule and budget. The schedule should include a sufficient number of milestones to manage decision points and interfaces (internal and external) and to monitor technical progress at different levels of the project.
SELI	**1.** Requirements Validation Trends **2.** Requirements Verification Trends **3.** Technical Measurement Trends
INCOSE Tracking	Requirements management status: • Defined • Validated

	• Verification method determined • Approved • Allocated • Traced to verification document (test procedure) • Designed • Implemented • Tested • Verified

EVM	The purpose of Requirements Management is to manage the requirements of the project's products and product components and to identify inconsistencies between those requirements and the project's plans and work products. • The ***project plans, activities, and work products*** are reviewed ***for consistency with the product requirements*** and the changes made to them.
SEI	Digital modeling provides us with another analytical tool--a coverage metric, which allows us to evaluate a current state of the model. In addition to calculating statistics of how many requirements are covered by test cases (Verify relationship) or design elements (Satisfy relationship), every metric records a time stamp. Periodically calculating the same metric allows the user to monitor changes of a specific aspect of the model in time. With MBSE, the record of authority shifts away from the documents to the digital model.
SW Modern-ization	3 Unifying Principles Resilient software must be defined first by execution stability, ***quality***, and dependable cyber-survivability. These attributes can be achieved at speed by aggressively adopting modern software development practices that effectively ***integrate performance*** and security throughout the software development lifecycle. More Than Code - Software modernization is more than just code development. It includes the many ***policies, processes, and standards that take a concept from idea to reality.*** Considerations such as ***contracting*** and intellectual property rights, as well as transition from development to fielding, are often overlooked and underappreciated. These policies, processes, and standards ***must not hinder, but empower the vision of this strategy.***

SEP	Introduction: • The SEP should include a digital ecosystem implementation plan that addresses the DE Strat goals and defines six key digital engineering ecosystem attributes … Applied elements of these attributes (requirements, models, digital artifacts, …) will be evident in the planning of the digital ecosystem implementation that results in the (ASoT) for the program • The SEP will describe a data management approach consistent with the DoD DE Strat. The approach should support maximizing the technical coherency of data as it is shared across engineering disciplines … Additional approaches to data management should at a minimum describe: o Digital artifact generation for reporting and distribution purposes
SEP	2.1 Requirements Development Program should maximize traceability and the use of models as an integral part of the mission, concept, and technical baseline to trace measures of effectiveness, measures of performance, and all requirements throughout the life cycle from JCIDS (or equivalent requirements authoritative source(s)) into a verification matrix, equivalent artifact, or tool that provides contiguous requirements traceability digitally. Program should trace all requirements from the highest level (JCIDS or equivalent requirements sources) to the lowest level (e.g., component specification or user story). This traceability should be captured and maintained in digital requirements management tools or within model(s). The system Requirements Traceability Matrix (RTM) should be a model output that can be embedded in or attached to the SEP, or the SEP should contain a tool reference location. …The matrix should include the verification method for each of the identified requirements and an indication whether each requirement is expected to change over the life of the program.
SEP	2.3 Specialty Engineering (SpEng) As part of the program's digital engineering approach, describe how models, simulations, the digital ecosystem, and digital artifacts will be used as part of an integrated approach to supporting SpEng activities and deliverables.
SEP	3.2.2 TPMs Technical Assessment Process … should include … a set of TPMs covering a broad range of core categories, rationale for tracking, **intermediate goals,** and the plan to achieve them with as-of dates (Table 3.2-***2***). (a)**This table was erroneously numbered "3.2-2." It should be "3.2.1."**

PSM DE measurement framework	2. MAJOR CONCEPTS Because DE processes help to define the capabilities of the eventual system, DE measures can serve as useful leading indicators for other product related measures. 8.7 DEPLOYMENT LEAD TIME Deployment Lead Time is a measure of how rapidly authorized requests for system capabilities and work products can be engineered, developed, and delivered for use in their intended operational environment. CYCLE TIME The elapsed time from when development work is started until the time development work has been completed and is ready for deployment. This time includes activities such as planning, requirements analysis, design, implementation, and testing. Base Measures 1: Completed Date: timestamp when authorized work completes development (design, implementation, integration, testing) and is authorized for deployment.
RIO	2.4.1 Ensure risk mitigation plans are reflected in the IMP, IMS, TPMs, and the EVM baseline. 3.2.1 Risk Identification Methodologies

	Assess technical performance at all levels: component, subsystem, integrated product, external interfaces. 3.4.5 develop a risk burn-down plan for all high and moderate risks and for selected low risks. A.4.2 Typical Contractor Responsibilities • Synthesize and correlate new and ongoing risk elements in the IMS, risk mitigation plans, estimates at completion, technical status documentation, and program updates and reviews. 5.5.1.2 Develop Strategies Establish effective metrics to monitor and manage the program. Planned metrics should consider recommendations for agile metrics per the DoD Agile Metrics Guide 5.5.2.5 Iterate • Review and update the risk register and backlog before each iteration. Reprioritize with the user based on feedback from previous iteration(s) and track accumulation of technical debt.
DOT&E	…commercial “agile software” development … published best practices ,,, include clear articulation of the capabilities required in the MVP, focused testing, comprehensive characterization of the product, and full delivery of the specified operational capabilities.

IMP/IMS	2.4 Digital Engineering Guidance Project schedules are digital models and should be integrated with other digital models of the project to support the project's DE effort.
SE Guidebook	2.2.4 Software Engineering Properly planned software engineering processes can mitigate cost and schedule risks by allowing DoD programs to identify and remove software-related technical debt early in development. This early action can increase acquisition efficiency and lead to higher success rates during operational testing and during operations and sustainment.
SE Guidebook	**Schedule Management** Include metrics to assess both schedule health,….associated completeness of the Work Breakdown Structure and the risk register. A healthy, complete and risk-enabled schedule forms the technical basis for the EVMS. Strong schedule metrics are paramount for accurate EVMS data. **Software Quality** Metrics should address software technical performance and quality (e.g., defects, rework) evaluating the software's ability to meet user needs **SE Role in Contracting** To adopt commercial best practices and advances, Program Management Offices (PMOs) should use the DoDI 5000.87 for software acquisition Incentive fees and penalties such as award fee may be tied to program performance …evaluated during technical reviews,
PB-EV	***Maintain bi-directional traceability*** of product and product component requirements among the project ***plans, work packages, planning packages, and work products***. Requirements traceability is a necessary activity of mapping customer needs to the system requirements and tracking how the system requirements are met throughout the development process—in the design, to system component development, through testing and system documentation, including for validation, verification, as well as to the project plans, and work products. CMMI® requires bi-directional traceability, that is, that evidence of an association between a requirement and its source requirement, its implementation, and its verification is established from the source requirement to its lower-level requirements, and from the lower-level requirements back to their source. A requirements traceability matrix is used to track the requirements.

DoDI 5000.87	(4) …define the MVP recognizing that an MVP's definition may evolve as user needs become better understood. Insights from MVPs help shape scope, requirements, and design. (11) Each program will develop and track a set of metrics to assess and manage the performance, (schedule) progress, speed, cybersecurity, and quality of the software development, its development teams, and ability to meet users' needs. Metrics collection will leverage automated tools to the maximum extent practicable. The program will continue to update its cost estimates and cost and software data reporting from the planning phase throughout the execution phase.
Agile Metrics	5.1.1 Story Points 5.1.7 Release Burnup Charts … measure the amount of work completed for a given release based on the total amount of work planned for the release. Usually, story points are used as the unit of measure to show planned and completed work. Additional Context Conceptually***, release burnup could be measured using requirements or user stories as the unit of measure*** as well. From the user perspective, understanding ***how many requirements are completed and how many remain might be a better way of communicating progress than story points.*** Additionally, like burndown charts, burnup charts can be applied to other scopes of work beyond releases (e.g., sprint burnup and product burnup). ***Variations*** ***• The number of requirements completed provides insight to users on requirements completed and requirements remaining.*** ***• The number of user stories completed is similar in concept to the metric showing the number of requirements completed.*** 5.2 Agile Quality Metrics 5.2.1 Recidivism Recidivism describes stories that are returned to the team for various reasons. 5.3 Agile Capability Delivery Metrics Agile capability delivery metrics measure delivery progress over time in alignment to desired ***outcomes*** (measured by value). 5.3.1 Delivered Features (or Delivered Capabilities) The count of delivered features measures the business-defined features accepted and delivered.
GAO Digital Twin	A high-fidelity digital twin, coupled with high-resolution simulations of the operating environment, can be used for testing the system to validate that it meets requirements.

Appendix B PB-EV Typical SE/DE work products/artifacts

PB-EV Table E-1: Typical SE/DE Work Products/Artifacts in CMMI	
CMMI Process Area	**Typical Work Products/Artifacts**
Requirements Development	Customer requirements Derived requirements Product requirements Product-component requirements Interface requirements Functional architectures Activity diagrams and use cases Object-oriented analyses with services identified Technical performance measures Records of analysis methods and results

PB-EV Table E-1: Typical SE/DE Work Products/Artifacts in CMMI	
CMMI Process Area	**Typical Work Products/Artifacts**
	Results of requirements validation

Technical Solution	Product component operational concepts, scenarios, and environments Use cases Documented relationships between requirements and product components Product architectures Product-component designs Technical data packages Allocated requirements Product component descriptions Key product characteristics Required physical characteristics and constraints Interface requirements Material requirements Verification criteria used to ensure requirements have been achieved Conditions of use (environments) and operating/usage scenarios, modes, and states for operations, support, training, and verifications throughout the life cycle Interface design specifications Interface control documents Implemented design Product support documentation (training materials, users manual, maintenance manual, online help.)
Requirements Management	Requirements traceability matrix
Validation	Validation results
Verification	Exit and entry criteria for work products Verification results
Measurement and Analysis	Specifications of base and derived measures
Decision Analysis and Resolution	Results of evaluating alternate solutions

PB-EV Table F-1 Trade Study Plan: Typical Work Products/Artifacts

Activity	**Trade Study Work Product/Artifacts**
1. Generate trade study plan	Trade study plan (based on time stamps of planned completion dates)
2. Establish objectives	Trade objectives
3. Establish evaluation criteria	Evaluation criteria
4. Define baseline candidates	Candidate definition: Include performance characteristics and / or models, engineering drawings, schematics, flow diagrams, equations etc.

5. Establish candidate evaluation methods: Approaches include preliminary design, analysis /evaluations, prototyping, simulation, analytical modeling, lessons learned, analysis	Evaluation methods
6. Establish interpretation guidelines	Interpretation guidelines
7. Trade study stakeholder review	Stakeholder review report
8. Evaluate candidates	Results of performing evaluation
9. Prioritize according to best fit	Trade study recommendations
10. Establish refinement criteria (if necessary): Accommodate new information	Refinement criteria and methods

Appendix C PSM DE measurement framework Artifacts

Appendix C PSM DE measurement framework Artifacts		
Artifact	**Description**	**Source**
Source Functional Requirement	Statement that identifies what results a product … shall produce; a function that a system or system component shall perform.	8.1 ARCHITECTURE COMPLETENESS AND VOLATILITY Function: A task, action, or activity that must be accomplished to achieve a desired outcome. A function may originate from source functional requirements, use cases, or functional decomposition.
Source Element	The base model elements defined per DE model from which other model elements shall be derived from or allocated to, e.g., a stakeholder needs.	8.2 MODEL TRACEABILITY The usefulness and quality of a digital model depends on the completeness and integrity of the relationships among model elements. Traceability between elements, such as requirements allocation and flow down to architectural, design, and implementation components, assures that the system solution is complete and consistent. Gaps in bi-

		directional traceability between the artifacts of two models or might indicate where further analysis or refinement are needed. The traceability concepts and indicators in this specification are representative examples of more general traceability mappings and reports across the development life cycle, such as: • Traceability between stakeholder needs, system requirements, and allocated or derived requirements at each level of the system hierarchy • Traceability and flow down of requirements to the logical or physical solution domain (e.g., design, implementation, integration, verification, validation) • Allocation and traceability of performance measures or parameters, such as Measures of Effectiveness (MOEs) or Key Performance Parameters (KPPs) • Traceability of system interfaces.

Appendix D

Excerpts from DOD INSTRUCTION 5000.97 DIGITAL ENGINEERING, December 21, 2023
Glossary:

DE: An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.

DE Ecosystem: The interconnected infrastructure, environment, and methodology (process, methods, and tools) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the stakeholders.

1.2. POLICY.

a. The DoD will conduct a comprehensive engineering program for defense systems, pursuant to DoD Instruction (DoDI) 5000.88. In support of that effort, the DoD will use DE methodologies, technologies, and practices across the life cycle of defense acquisition programs,… engineering, and management activities.

b. DoDI 5000.88: certain programs must include a DE implementation plan in the SE plan.

2.7. DOD COMPONENT HEADS WITH ACQUISITION AUTHORITY.

(2) Provide guidance and support for program managers to develop, validate, and maintain:

(a) Credible and coherent authoritative sources of truth (ASOT) shared with stakeholders.

(b) Digital models that accurately reflect the architecture, attributes, and behaviors of the system they represent.

3.1 DE

c. Uses computer systems for the development, verification, validation, use, curation, configuration management, and maintenance of technically accurate digital models in support of system life-cycle activities. These models capture system representations and, together with their underlying data, provide an authoritative source of truth (ASOT).

d. Moves the primary means of communicating system information from documents to digital models and their underlying data.

3.2 DE CAPABILITY.

b. DE Capability Elements.

3.2 DIGITAL ENGINEERING CAPABILITY.

(2) Digital Models (Including Digital Twins).

(b) Configuration control must be maintained on digital models and digital twins. Digital models, including their information and data, should be traceable from operational capabilities through requirements, design constructs, production, test, training, and sustainment. The use of this data should be considered during the program planning and the acquisition and contracting phases of the system's life cycle to ensure…the system will remain functional, sustainable, upgradable, and affordable. Programs should verify and validate the baseline(s) of digital model(s) before technical milestones. Digital model types include, but are not limited to:

1. Requirements models.
2. Structural models.
3. Functional models.

(3) Digital Threads.

(b) The digital thread allows different audiences with different perspectives to extract data from and adjust usage of models to carry out different activities, including, but not limited to:

1. Requirements analysis.
2. Architecture development.
3. Design evaluation and optimization.
4. System, subsystem, and component definition and integration.
5. Cost estimating.
6. Training aids and devices development.
7. Developmental and operational tests.

(4) Digital Artifacts.

Digital artifacts are the digital products and views that can be dynamically generated directly from digital models. These artifacts are created from the standards, rules, tools, and infrastructure within a DE ecosystem. Some

common examples of digital artifacts include, but are not limited to:
(a) Design specifications.
(b) Technical drawings (e.g., authorization boundaries, data flows).
(c) Design documents.
(d) Interface management documents.
(e) Analytical results.
(f) Bills of material.
(g) Software source code.
(h) Work breakdown structure.
(i) Production or machining instructions.
(j) Test planning and cases.
(k) Schedules.

3.4. IMPLEMENTATION OF DIGITAL ENGINEERING.

b. The PM will identify and require digital models, artifacts, and data sets as deliverables in the contract through contract data requirements lists and data item descriptions.

3.5. PROCEDURES FOR MAINTAINING DIGITAL MODELS AND AUTHORITATIVE DATA SOURCES.

a. Digital Models.

(1) Programs will identify and maintain model-centric baselines, approaches, and applications in a digital form that integrates the technical data and associated digital artifacts that stakeholders generate throughout the system life cycle.

b. Authoritative Data.

Programs should develop and implement plans to establish current, consistent, enduring, and authoritative sources of truth for digital models and data.

3.5. PROCEDURES FOR MAINTAINING DIGITAL MODELS AND AUTHORITATIVE DATA SOURCES.

a. Digital Models.

(1)…The program should develop digital model(s) using standard and best practice model representations, methods, and underlying data structures to maximize interoperability.

(4) Programs will ensure digital models, simulations, and associated data are verified, validated, and accredited for their intended use, in accordance with DoDI 5000.61.

Appendix E Excerpts from CMMI-DEV, V1.3

Requirements Development

In Agile environments, customer needs and ideas are iteratively elicited, elaborated, analyzed, and validated. Requirements are documented in forms such as user stories, scenarios, use cases, product backlogs, and the results of iterations (working code in the case of software). Which requirements will be addressed in a given iteration is driven by an assessment of risk and by the priorities associated with what is left on the product backlog. What details of requirements (and other artifacts) to document is driven by the need for coordination (among team members, teams, and later iterations) and the risk of losing what was learned. When the customer is on the team, there can still be a need for separate customer and product documentation to allow multiple solutions to be explored. As the solution emerges, responsibilities for derived requirements are allocated to the appropriate teams. (See "Interpreting CMMI When Using Agile Approaches" in Part I.)

Configuration Management

The Configuration Management process area involves the following activities:

- Identifying the configuration of selected work products that compose baselines at given points in time
- Controlling changes to configuration items
- Building or providing specifications to build work products from the configuration management system
- Maintaining the integrity of baselines
- Providing accurate status and current configuration data to developers end users, and customers

The work products placed under configuration management include the products that are delivered to the customer, designated internal work products, acquired products, tools, and other items used in creating and describing these work products. (See the definition of "configuration

Examples of work products that can be placed under configuration management include the following:

- Hardware and equipment
- Drawings
- Product specifications
- Tool configurations
- Code and libraries
- Compilers
- Test tools and test scripts
- Installation logs
- Product data files
- Product technical publications
- Plans
- User stories
- Iteration backlogs
- Process descriptions
- Requirements
- Architecture documentation and design data
- Product line plans, processes, and core assets

Quantitative Project Management

The Quantitative Project Management process area involves the following activities:

- Establishing and maintaining the project's quality and process performance objectives
- Composing a defined process for the project to help to achieve the project's quality and process performance objectives
- Selecting subprocesses and attributes critical to understanding performance and that help to achieve the project's quality and process performance objectives
- Selecting measures and analytic techniques to be used in quantitative management

Excerpts from 2019 NDIA SE Div. Input to 2018 DoD Defense Science (DSB) Board Report *Design and Acquisition of Software for Defense and from DSB Report*

DSB Excerpts:
Background

Recommendation 2: Continuous Iterative Development
The DoD and its defense industrial base partners should adopt continuous iterative development best practices for software, including through sustainment.

The **Service Acquisition Executives (SAE)**, with the **program executive officers (PEOs)**, the **program managers (PMs)**, and the **Joint Staff/J-8**, should, over the next year, identify minimum viable product (MVP) approaches and delegate acquisition authority to the PM (cascade approach), providing motivation to do MVP and work with the users to:

- deliver a series of viable products (starting with MVP) followed by successive next viable products (NVPs);
- establish MVP and the equivalent of a product manager for each program in its formal acquisition strategy, and arrange for the warfighter to adopt the initial operational capability (IOC) as an MVP for evaluation and feedback; and

NDIA Excerpts:
NDIA, in collaboration with the International Council on SE (INCOSE) and PSM has volunteered to provide input to USD(A&S) and USD(R&E) representing the "industry perspective" on implementation of the DSB recommendations.

While the DSB report focuses primarily on SOFTWARE design and acquisition using continuous and iterative methods, NDIA believes that the scope must be expanded to focus on SYSTEM design and acquisition using continuous and iterative methods.

Steering at lower levels is integrated with roadmap updates and MVP/Next Viable Product (NVP) planning.
• Contracts defined by MVP: Contracting approach includes mechanisms for flexibly defining and approving MVP/NVP capabilities.

DSB #1: Software Factory Picture of Success (end-state):
Soft link all of the tools in the value stream to deliver software. Review that all of the tools are soft linked.
• Requirements Tools
• Product Backlog
• Master Schedule
• Models
• Repository
• Test Tools
• Deployment Tools that demonstrates end-to-end traceability

DSB #2: Continuous Iterative Development

NDIA INCOSE PSM

Continuous Iterative Development

… identify Minimum Viable Product (MVP) approaches … to:

- deliver a series of viable products (starting with MVP) followed by successive Next Viable Products (NVPs);
- establish MVP and the equivalent of a product manager for each program in its formal acquisition strategy, and arrange for the warfighter to adopt the Initial Operational Capability (IOC) as an MVP for evaluation and feedback; and

NDIA Excerpts continued:

DSB #3b: Metrics
EVM for CID Programs

Earned Value Management (EVM) has often problematic when applied to agile or software CID programs, with uncertain delivery outcomes that may vary based on iteration, priorities, and stakeholder input.

Where EVM is required, NDIA recommends aligning EVM with emerging best practices: (PARCA, NDIA, SEI, …)

- Contracting for CID programs
- Integration of CID planning with EVM processes and PMB (e.g., WBS, IMP, IMS, ETC/EAC, BCWP, BCWS, ACWP, % complete tracking, CV, SV)
- Adapt CID measures for planning and managing work package EVM performance
- Using EVM to managing baseline changes on CID programs

Recommend tailoring DoD policies and guidance (e.g., DODI 5000.02) to better integrate effective PM practices for software-intensive programs.

Appendix G, page 1 of 2

2006 INCOSE International Symposium paper, "Using Earned Value to Track Requirement Progress," by Paul Solomon, July 2006

Note: A PDF of this paper may be downloaded from www.pb-ev.com, at the White Papers" tab.

Excerpts:

It is necessary to track the status of each requirement as it moves through engineering life cycle activities. Measures that reflect the status of the requirements are essential to monitor program status and serve as a scorecard to indicate that requirements are being implemented on schedule. This paper provides guidance to use the tools of requirements traceability to plan and measure the progress of the requirements management activities. The requirements traceability matrix (RTM) can be used as a scheduling source and as a set of base measures of Earned Value (EV). Finally, the importance and value of comparing the schedule variances of the requirements management and tracing activities with the variances of other project activities is discussed.

Progress.

It is important to quantify the progression of requirements from concept to formulation to design to test. Peter Baxter discusses assessing these requirements to ensure that your product contains all required functionality. Baxter's advice addresses software requirements but is also applicable to the system requirements: It is advisable to measure the number of requirements that each software process generates or accepts. Measure the number of system or top-level software requirements (i.e. features or capabilities), as well as the decomposition of system requirements into more detailed requirements. In order to track differences between developed and planned requirements, it is necessary to also measure the status of each requirement as it moves through life cycle activities. A typical requirement status could be: defined, approved, allocated, designed, implemented, tested, and verified. A measure that shows the status of all requirements is essential in monitoring program status and acts as a scorecard to illustrate that requirements are being implemented. Early in the program schedule, ensure that requirements become defined, approved, and allocated as the system architecture is finalized. Near the end of the program schedule, you should see requirements move from implemented status, to tested, then to verified status (Baxter 2002). Measuring the status of each requirement as it moves through life cycle activities is an essential control tool for effective project management.

Recommended Requirements Statuses

To recap, a recommended set of requirements management statuses is:

- Defined
- Validated
- Verification method determined
- Approved
- Allocated
- Traced to verification document (test procedure)
- Designed
- Implemented
- Tested
- Verified

When determining which project activities and work products should be discretely scheduled and tracked, PMs regard the RTM as a tool, not as a work product. They propose that populating the RTM with data is a support activity to the real work products of engineering development (designs, test articles, test results etc.). They also argue that the actual completion of many of activities listed above, as well as the associated documents, is the responsibility of other engineers, not the requirements management engineers. They then point to those who are actually doing the designing or testing or making related decisions. Consequently, the requirements engineers conclude that, if the allocated requirements have not been implemented into the design on schedule, or the test procedure does not yet include all necessary test cases, or the verification of requirements is behind schedule, it's not their fault. Therefore, they propose, their activities should be measured as LOE. It is recommended that, regardless of accountability, the progress of requirements, as they progress through the engineering life cycle, should be scheduled and measured against a plan. Of course, discrete earned value techniques should be used for management control. Even though the budget for the requirements engineers may be relatively small, as compared with the budgets for all other engineers, the earned value taken in control accounts or work packages for requirements management activities can be the most important indicator of project schedule performance. The schedule status of the set of requirements reveals more about the health of the project than any other schedule performance indicator in the Performance Measurement Baseline (PMB).

Conclusions

If the requirements management and traceability activities are behind schedule, it is an early warning that the rest of the project is or will be in trouble. We recommend that a PM look at the progress and schedule variance of these activities early in any review. The requirements management and traceability activities should be discretely planned and measured. If these activities are realistically planned, they provide a valid basis for Outcome-based metrics (published as "Performance-based EV") and give the PM insight into progress of the total program.

Appendix H PSM Excerpts

Many of the measurable benefits of DE are associated with the use of both data and validated digital models as a "source of truth" across life cycle activities.

Page 3
Thus, DE has three interrelated concerns: the transformation of engineering activities to fully digital infrastructure, artifacts, and processes; the use of authoritative sources of data and models to improve the efficiency and productivity of engineering practice; and the use of MBSE practice to fully integrate system data and models with engineering, program management, and other domains and disciplines.

Page 9
DE measures can serve as useful leading indicators for other product related measures. DE can produce additional products in support of delivered data, hardware, and software products such as digital twins or other model- or simulation-based executable systems.

Page 54
In a DE environment products are model-driven, providing additional opportunities to cost-effectively incorporate changes to digital models that are directly traceable to the implemented and tested work products, some of which can be automatically generated.
59
Model-based work products such as requirements, architecture, design, use cases and other views or modeling artifacts can be automatically generated and published directly from modeling tools, at significant savings in effort relative to traditional documentation-centric approaches. Model-driven automation based on an Authoritative Source of Truth (ASoT) can lead to process efficiencies, labor reductions, shorter cycle times, less rework, and earlier verification and validation of solutions.

8.1 MODEL TRACEABILITY

Measure Introduction	
Description	The usefulness and quality of a digital model depends on the completeness and integrity of the relationships among model elements. Traceability between elements, such as requirements allocation and flow down to architectural, design, and implementation components, provides assurance that the system solution is complete and consistent. Gaps in bi-directional traceability within a digital model can indicate where further analysis or refinement are needed. Traceability also supports impact assessments as a result of engineering changes. Traceability reports and analyses are greatly facilitated by modern digital modeling tools. The traceability concepts and indicators in this specification are representative examples of more general traceability mappings and reports across the development life cycle, such as: • Traceability between stakeholder needs, system requirements, and allocated or derived requirements at each level of the system hierarchy • Traceability and flow down of requirements to the logical or physical solution domain (e.g., design, implementation, integration, verification, validation) • Allocation and traceability of performance measures or parameters, such as Measures of Effectiveness (MOEs) or Key Performance Parameters (KPPs) • Traceability of system interfaces
Relevant Terminology	Model element — Modeling constructs used to capture the structure, behavior, and relationships among system model components.

Appendix I Project Management Best Practices in Capability Maturity Model Integration (CMMI®) Model V3.0

Best Project Management Leading Practices from ISACA CMMI Model V3.0 per GAO Report GAO-24-106886	
Practice Number	**Practice Statement**
Requirements Development and Management (RDM) RDM 2.4	Develop, record, and keep updated bidirectional traceability among requirements and activities or work products.
RDM 2.5	Ensure that plans and activities or work products remain consistent with requirements.
RDM 3.4	Identify, develop, and keep updated interface or connection requirements.
RDM 3.7	Validate requirements to ensure the resulting solution will perform as intended in the target environment.
Product Integration (PI) PI 3.1	Review and keep updated interface or connection descriptions for coverage, completeness, and consistency throughout the solution's life.
Risk and Opportunity Management (RSK) RSK 3.5	Manage risks or opportunities by implementing planned risk or opportunity management activities.
Supplier Agreement Management (SAM) SAM 4.1	Select measures and apply analytical techniques to quantitatively manage suppliers against their performance targets.
Verification and Validation (VV) 1.1	Perform verification to ensure the requirements are implemented and record communication results.
VV 1.2	Perform validation to ensure the solution will function as intended in its target environment and record communication result.
VV 3.1	Develop, keep updated, and use criteria for verification and validation.
VV 3.2	Analyze and communicate verification and validation result.

Appendix I Artifacts, Milestones, and Metrics to Use for Embedded Software When EVMS is Required

Source Table 3:

SEP	**3.2.9 Config. and Change Management** **Technical Baseline Artifacts** – …At a minimum, describe the artifacts of the concept, functional, allocated, and product baselines and when each technical baseline has been or will be established and verified. If practicable, the PM will establish and manage the technical baseline as a digital authoritative source of truth.	Verified Add: ***The product baseline includes the sequential set of MVP/MVCR baselines as appropriate.***

Source Appendix A:

INCOSE Tracking	Requirements management status: • Defined • Validated • Verification method determined • Approved • Allocated • Traced to verification document (test procedure) • Designed • Implemented • Tested • Verified

PB-EV	***Maintain bi-directional traceability*** of product and product component requirements among the project ***plans, work packages, planning packages, and work products***. Requirements traceability is a necessary activity of mapping customer needs to the system requirements and tracking how the system requirements are met throughout the development process—in the design, to system component development, through testing and system documentation, including for validation, verification, as well as to the project plans, and work products. CMMI® requires bi-directional traceability, that is, that evidence of an association between a requirement and its source requirement, its implementation, and its verification is established from the source requirement to its lower-level requirements, and from the lower-level requirements back to their source. A requirements traceability matrix is used to track the requirements.

DoDI 5000.87	(4) …define the MVP recognizing that an MVP's definition may evolve as user needs become better understood. Insights from MVPs help shape scope, requirements, and design. (11) Each program will develop and track a set of metrics to assess and manage the performance, (schedule) progress, speed, cybersecurity, and quality of the software development, its development teams, and ability to meet users' needs. Metrics collection will leverage automated tools to the maximum extent practicable. The program will continue to update its cost estimates and cost and software data reporting from the planning phase throughout the execution phase.
Agile Metrics	5.1.1 Story Points 5.1.7 Release Burnup Charts … measure the amount of work completed for a given release based on the total amount of work planned for the release. Usually, story points are used as the unit of measure to show planned and completed work. Additional Context Conceptually***, release burnup could be measured using requirements or user stories as the unit of measure*** as well. From the user perspective, understanding ***how many requirements are completed and how many remain might be a better way of communicating progress than story points.*** Additionally, like burndown charts, burnup charts can be applied to other scopes of work beyond releases (e.g., sprint burnup and product burnup). ***Variations*** ***• The number of requirements completed provides insight to users on requirements completed and requirements remaining.*** ***• The number of user stories completed is similar in concept to the metric showing the number of requirements completed.*** 5.2 Agile Quality Metrics 5.2.1 Recidivism Recidivism describes stories that are returned to the team for various reasons. 5.3 Agile Capability Delivery Metrics Agile capability delivery metrics measure delivery progress over time in alignment to desired ***outcomes*** (measured by value). 5.3.1 Delivered Features (or Delivered Capabilities) The count of delivered features measures the business-defined features accepted and delivered.

Appendix J Commercially Available Tool to Use a Digital Twin

Excerpts from one commercial vendor's solution to "prepare to transform your product development process with verification management solutions leveraging a digital twin" follow.

Appendix K Excerpts DoDI 5000.61. DOD MODELING AND SIMULATION VERIFICATION, VALIDATION, AND ACCREDITATION. September 17, 2024

1.2. POLICY. a. Models, simulations, distributed simulations, and associated data used to support DoD processes, products, and decisions:
(1) Undergo verification and validation (V&V) throughout their life cycles.

SECTION 3: VV&A DOCUMENTATION REQUIREMENTS
3.1. VV&A DOCUMENTATION.
b. V&V Implementation and Results Information.
(1) Descriptions of the V&V activities and results.
(2) Summary of results, including the capabilities, limitations, risks, potential impacts to the specific intended use, and assumptions of the model, simulation, distributed simulation, and associated data undergoing V&V.

G.2. DEFINITIONS.

Validation
The process of determining the degree to which a model, simulation, or distributed simulation, and associated data are an accurate representation of the real world from the perspective of the specific intended use. Validation across the M&S life cycle entails application of relevant referent data to refine M&S accuracy.

Verification
The process of determining that a model, simulation, or distributed simulation, and associated data accurately represent the developer's conceptual description and specifications.

Appendix L Excerpts from AFMC white paper, "DMM: An Accelerated Future State,"

Integrated tools built on models, data, and infrastructure yield radical transparency.

PROGRAM MANAGEMENT

DMM means better insight for program managers. Product Lifecycle Management (PLM) tools capable of integrating models and data from across the functionals allow program managers to make informed decisions impacting every aspect of a program. A program manager can see ***the status of all deliverables, the status of all integrated product teams, and the current production status all in one view.*** This insight allows for better program management and more rapid integrated capability delivery.

FINANCIAL MANAGEMENT

DMM means ***instant access to current budget, cost, and program execution data*** for financial managers. System performance models can rapidly reflect cost considerations in design trade-space analysis, allow financial professionals to execute a series of 'what-if' analyses to work towards an optimal solution for the enterprise, and streamline Financial Improvement and Audit Readiness (FIAR) compliance for all lifecycle phases.

Appendix M Excerpts from DoD Guide Software Engineering for Continuous Delivery of Warfighting Capability

4.1 Requirements Best Practices

- Develop a core set of requirements that define the MVP or MVCR
- The MVP/MVCR reflects the core set of mandatory features the software must have to deliver value to operational users.
- Epics and features may be defined for the MVP or upcoming releases
- Stories, tasks, and activities should not be included in a product roadmap. (This is not a project schedule or an Integrated Master Schedule).
- Capture requirements as test cases incorporated into automated test suites as part of a test-driven development approach
- Address functional requirements (functions the system performs for the user)
- Track and prioritize requirements (Product Backlog) using automated tools that integrate with the development pipeline

5.1 Distinction between Waterfall and Agile/DevSecOps Metrics

Agile/DevSecOps metrics focus on…delivery and quality…different set of metrics from Waterfall.

…using as much automation as possible.

…metrics to assess and manage the (technical) performance, progress, cybersecurity, and quality of the software development.

5.2.3 Technical Debt

If left unchecked, mounting technical debt can overwhelm a program with unplanned work to address…poor system performance, stability, and maintainability.

Claim: Addressing an increasing technical debt workload can have major impacts on productivity…leading to cost and schedule impacts.

5.3.3 Qualities of a Useful Software Metric

A software metric must be consequential (connect to a program, project, or software development *outcome*. (outcome-based metrics)

5.6 Technical Performance Metrics

Develop technical measures of mission effectiveness to augment the software process metrics.

5.8.2 Function-Related Metrics

Function-related metrics...function points (not story points).

7.7 Product Roadmap

- The product roadmap should be traceable both to the product vision, required capabilities and to the product backlog
- The product roadmap should address early delivery of the MVP and MVCR
- The product roadmap is best supported by automated tools.

Appendix N

PMBOK® Guide 7th Edition Excerpts	
Subject	**Description**
Artifacts	Planning activities and artifacts need to remain integrated throughout the project. This means that planning for the performance in terms of (product) scope and quality requirements aligns with delivery commitments.
Measures of performance.	Measures of performance characterize physical or functional attributes relating to the system operation. Examples include size, weight, capacity, accuracy, reliability, efficiency, and similar performance measures.
Metric	A description of a project or product attribute and how to measure it. Metrics associated with the product are specific to the deliverables being developed. As part of planning, the metrics, baselines, and thresholds for performance are established, as well as any test and evaluation processes and procedures that will be used to measure performance to the specification of the project deliverable. The metrics, baselines, and tests are used as the basis to evaluate variance of actual performance. A performance review of project results against the project baselines *and other measurement metrics* demonstrates that the project is progressing as planned. Misusing the metrics: Regardless of the metrics used to measure performance, there is the opportunity for people to distort the measurements or focus on the wrong thing. Examples include focusing on less important metrics rather than the metrics that matter most.
Minimum Viable Product	A concept used to define the scope of the first release of a solution to customers by identifying the fewest number of features or requirements that would deliver value.
Quality	Quality focuses on the performance levels that are required to be met. Quality requirements may be reflected in the completion criteria, definition of done, statement of work, or requirements documentation.
Quality Metrics	A description of a project or product attribute and how to measure it.
Product Breakdown Structure	A hierarchical structure reflecting a product's components and deliverables.
Product	An artifact that is produced, is quantifiable, and can be either an end item in itself or a component item.
Product scope	The features and functions that characterize a product.
Requirements	Requirements become the foundation of the WBS. Cost, schedule, quality planning, and procurement are all based on these requirements.
Requirements Baseline	Unambiguous (measurable and testable), traceable, complete, consistent, and acceptable to key stakeholders. Components include, functional requirements, non-functional requirements, quality requirements, and acceptance criteria.

Requirements Management Plan	A component of the project or program management plan that describes how requirements will be analyzed, documented, and managed.
Requirements Traceability Matrix	Links product requirements from their origin to the deliverables that satisfy them.
Rework	Action taken to bring a defective or nonconforming component into compliance with requirements or specifications.
Risk management plan	A component of the project, program, or portfolio management plan that describes how risk management activities will be structured and performed.
Risk responses	Risk responses are aligned with the prioritization of project constraints, such as budget, schedule, and performance.
Technical performance measures	Quantifiable measures of technical performance are used to ensure system components meet technical requirements. They provide insights into progress in achieving the technical solution.

Appendix O Excerpts from DSB Reports

DSB Test and Evaluation (T&E) study

Appendix D. Summary of Findings and Recommendations

	Findings	Recommendations
	Strategic Shift in T&E	

3 Continuous Testing	• Continuous testing offers pathway for improving T&E efficiency through continual evidence accrual.
	  • A structured digital engineering framework is essential for aligning development, simulation, and testing activities.
	• Significant automated testing will be required to cover operational "envelop" of complex systems.
		• **USD(A&S) should direct Service Acquisition Executives** to structure new programs to:
		  • incorporate testability requirements in components, subsystems, and systems to speed evidence accrual;
		  • maximize use of automation to increase testing for systems and subsystems; and
		  • develop approaches to report system status and data to enable feedback for improving system performance.
		• **USD(R&E) should direct DTE&A** to develop and promulgate DT guidance to ensure system capability to use automated developmental testing to the maximum extent possible.

		to programs and subsequent operational testing.
	Enablers to Future T&E	

6 Digital Engineering	• Digital engineering will be essential to augment and complement T&E but will not replace the need for live testing.
	• Increasing T&E efficiencies through digital engineering will require aligning T&E and M&S tools to well-defined interfaces and its use as the authoritative source of system data with continual evidence accrual.
	• Government program offices and the T&E community are often not prepared, educated, and resourced to operate in a fast-paced digital engineering environment.
		• **DTE&A** should publish best practices on use of digital engineering principles to fully realize opportunity for increasing developmental testing efficiency and speed.
		  • Align system and subsystem interfaces to existing standards where available; facilitate development of critical new interface standards.
		  • Align M&S tools to system and subsystem interfaces to enhance testing strategies.
		  • Plan for structured evidence accrual during development and testing to validate performance.
		• **USD(A&S) should work through Service Acquisition Executives** to:

DE Capability to Automate Testing and Evaluation–Final Product

Executive Summary

Through an analysis of DE use in both defense and commercial industries, the Task Force found that DE, when properly applied, can improve cost, schedule, and performance of complex projects and programs.

To facilitate this transition from document to model-centric systems engineering, the Task Force created a checklist of critical steps programs and portfolios should follow when considering DE implementation which can be found in Appendix C in this report.

Appendix C: Digital Engineering Checklist for Programs and Portfolios

…pursue a MBSE-first approach in all acquisition pathways, strategies, and contracts. Key actions include capturing data systematically across the life cycle including evidence of cost, schedule, performance, and agility of MBSE.