Integrating the Embedded Software Path, Model-Based Systems Engineering, MOSA, and Digital Engineering with Program Management January 17, 2024

Paul Solomon

Note:
This revision incorporates DODI 5000.97 DIGITAL ENGINEERING (DE), December 21, 2023.

For a bird's eye, but outdated, view of this white paper, first read the *Defense Acquisition Magazine* article, "Better Program Management Through DE," May/June 2022. It provides guidance to unite DE with the Advanced Acquisition Framework for cost-effective program management of software-intensive major capability acquisitions and other acquisition pathways.

A future revision of this white paper will add Artificial Intelligence (AI) to the DE ecosystem. The enhanced ecosystem will enable better baseline planning, measurement, and variance analysis. AI will also be used to provide requirements traceability to the schedule for better integrated program management during planning and analysis. AI's predictive capability will generate estimates at completion.

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 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.

Per 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 authoritative sources of truth (ASOT) shared with stakeholders.
(b) Digital models that accurately reflect the architecture, attributes, and behaviors of the system they represent.

Pertinent excerpts from DODI 5000.97 are in Appendix D.

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:

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)

The metrics are needed to inform the PM:

1. If the definitions of the technical baselines (functional, allocated, product), and if applicable Minimum Viable Product (MVP), and Minimum Viable Capability Release (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.

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.

Information Needs of USD(A&S)

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.

Information 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.

  Afternote:

Sec. of the AF Kendall commented on DE in his address to the Defense Writers Group on May 22, 2023. Regarding the challenges in implementing DE, he stated that "integrated digital designs, better modeling…don't replace testing…you've got to get it into testing to validate your design efforts."

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.

- **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/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.

  Include technical debt in DoDI 5000.88, Engineering of Defense Systems and the Engineering of Defense System Guidebook.

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.

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.

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 DEMWG 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 pertinent DAS overarching policies and objectives are considered to be ASOT 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 the *Practical Software and Systems Measurement (PSM) Digital Engineering Measurement Framework,* Version 1.0c June 21, 2022. (*PSM DE measurement framework*). 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.

- DoD Instruction (DoDI) 5000.80, Middle Tier of Acquisition
- DoD Instruction (DoDI) 5000.85, Major Capability Acquisition
- DoDI 5000.87, Software Acquisition
- DoDI 5000.88, Engineering of Defense Systems
- DoDI 5000.89, Test and Evaluation
- DoD DE Strat
- DoD Software Modernization Strategy (SW Modernization)
- DoD OSD Best Practices for Using SE Standards (ISO/IEC/IEEE 15288, IEEE 15288.1, and IEEE 15288.2) on Contracts for DOD Acquisition Programs (15288BP)
- Software Engineering Institute (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)
- D0D Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs (Risk)
- DOT&E
- DoD IMP/IMS
- Engineering of Defense Systems Guidebook
- GAO-20-590G *GAO Agile Assessment Guide* (GAO Agile)
- 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
- SE Leading Indicators Guide (SELI)
- 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" (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)

Recommended revisions to DAS, DoDI 5000.80, DODI 5000.87, DODI 5000.88, DODI 5000.89, DE Strat and SEP 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.	performance Insert: technical objectives 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 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)
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

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 twork 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, and PB-EV. 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.

Appendix A ASOT for Selecting DE Metrics and Typical DE Artifacts

ASOT for Selecting DE Metrics and Typical DE Artifacts	
Doc.	**Excerpts**
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)
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.
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.
SELI	**1.** Requirements Validation Trends **2.** Requirements Verification Trends **3.** Technical Measurement Trends

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.
Risk	3.2.1 Risk Identification Methodologies

	Assess technical performance at all levels: component, subsystem, integrated product, external interfaces.
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.
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.

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 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).

3.2 DE CAPABILITY.

b. DE Capability Elements.

(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.