Integrating the Embedded Software Path, Model-Based Systems Engineering, and Digital Engineering with Program Management Dec 26, 2021

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> Note: This revision includes references to David Cadman's keynote address at the recent NDIA Systems and Mission Engineering Conference, excerpts from my letter to another keynote speaker at that conference, Undersecretary of Defense Heidi Shyu, and references to my tutorials at previous NDIA conferences. We have common objectives.

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:

- Use the embedded software path to develop software embedded in weapon systems
- Employ digital engineering (DE) metrics
- 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.

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, and quality:

- DE Strat
- DoD Instruction 5000.87 Operation of the Software Acquisition Pathway (5000.87)
- DoD Instruction 5000.88 DoDI Engineering of Defense Systems (5000.88)
- DoD Instruction 5000.89 DoDI Test and Evaluation (5000.89)
- DoD SE Plan Outline (SEP)

The metrics are needed to inform the PM:

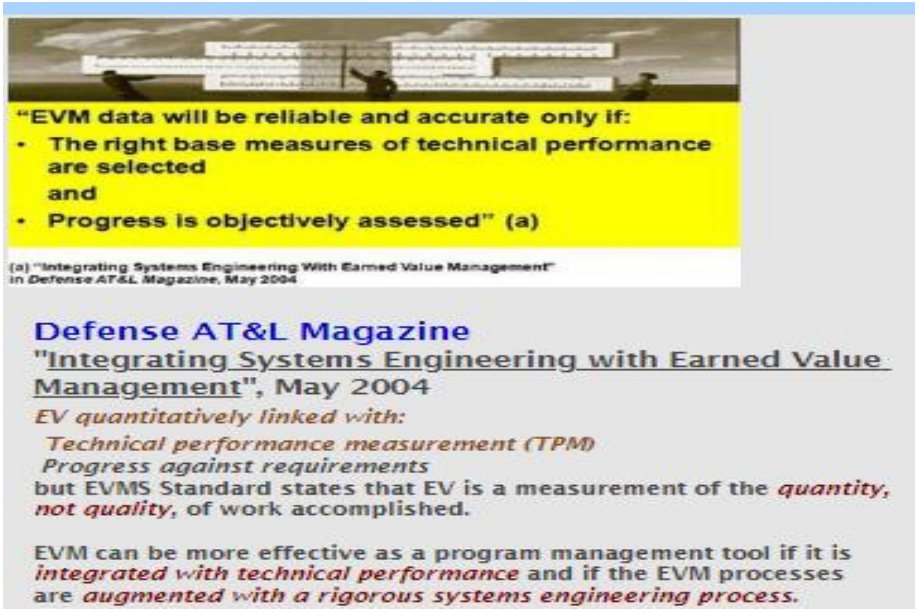
- If the definitions of the technical baselines (functional, allocated, product, and if applicable Minimum Viable Product (MVP), and Minimum Viable Capability Release (MVCR), will be completed on schedule.
- If the needed capabilities, features, and functions will be delivered on schedule.

At the recent NDIA Systems and Mission Engineering Conference, David Cadman, acting assistant secretary of defense for acquisition enablers, addressed a PM's needs regarding MVP's and the integration of earned value management (EVM) with systems engineering (SE), as follows:

> "We've opened up the software pathway with this idea of [yielding] a MVP with these quick updates and deliveries. "
>
> "If you're not doing earned value, what are you doing? I mean, you can't be unmanaged when you do your program."
>
> "So, I'm not saying I know what the best way to do business is, but why don't you work with us to try to figure out what is the best way to manage programs."

Another keynote speaker at that conference was Under Secretary of Defense, Research and Engineering Heidi Shyu. In my letter to USD Shyu, dated Dec. 16, I reiterated a recommendation to manage programs better by "Integrating SE with EVM." Excerpts from that letter follow.

> Additional rationale for my recommendations is provided in my 2004 article in *Defense AT&L Magazine,* "Integrating SE with EVM." Despite the potential of DE to deliver performance faster using data-driven analysis, programs such as the Ground-Based Strategic Deterrent Program may encounter the same fate as programs which use EVM; schedule slips, Over Target Baselines, and Nunn-McCurdy breaches. You can mitigate these risks if the right base measures of technical and schedule performance are employed with proper contractual direction and incentives. The article is still relevant even if EVM is not contractually-required. Excerpts follow:



Practical and contractual advice to do integrate SE with EVM was presented in tutorials at NDIA SE conferences beginning in 2005. The last NDIA tutorial was in 2019, entitled **"Integrate SE with EVM and Program Management, Contractually and Practically."** An updated version was presented at the Naval

Postgraduate School in March 2020. That tutorial may be downloaded from www.pb-ev.com at the "Articles and Tutorial" tab.

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.

1. **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 DR best practices and to leverage DE. Excerpts follow.

   Excerpts of NDAA provision:

   The Sec. of the AF shall conduct a review…include the following:

   - An analysis of the ability of the AF to implement industry best practices regarding DE during the EMD phase
   - 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.
   - A review of the ability of the AF to leverage DE during such EMD phase.
   - Recommendations to improve the cost, schedule, and program management of the EMD phase

2. **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 technical performance measures (TPM) 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.

3. **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.

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*."

The Sec. 809 Report's assessment indicates that DoD's EVM commitments to Congress in 2009 and 2014 have not been met. The PARCA 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. 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.* Also, the DE Metrics Working Group (DEMWG) should develop and publish those metrics. DE *and program management should be integrated and not stove-piped*.

Recommendations

Recommendations are provided herein that define the PM's information needs and the DE metrics that meet those needs. Recommended digital artifacts that should be considered as base measures of the DE metrics are also provided in Appendix 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 modeling and simulation,* 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.

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 meet the information needs.

The recommended DE metrics should be used as digital authoritative sources of truth (ASOT) to

a. Develop the schedule plan for defining requirements in automatedly-linked scheduling systems.
b. Assess schedule progress for defining and completing requirements in automatedly-linked scheduling systems.
c. Use digital artifacts as base measures of DE metrics as ASOT that SE work products are completed such as:
    i. Requirement definitions including approved technical performance measures (TPM), verification methods, and completion criteria in the functional and allocated baselines.
    ii. Trade studies
    iii. Completed products in the product baseline including the MVP and MVCR baselines, if applicable
    iv. 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 modeling and simulation***, 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 Practical Software and Systems Measurement (PSM) Information Categories and Measurable Concepts in Table 2.

Table 2 PSM Information Categories and Measurable Concepts	
Information Category	**Measurable Concept**
Schedule and Progress	Work Unit Progress
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 5000.85, Major Capability Acquisition (DoDI 5000.85)
- DoDI 5000.87
- DoDI 5000.88
- DoDI 5000.89
- DE Strat
- Defense Acquisition Guidebook (DAG)
- 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, 2021
    - Benefits and Challenges of MBSE, July 2021
- SEP
- 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 5000.87, 5000.88, 5000.89, DE Strat, and SEP are included Table 3. ASOT for selecting DE metrics and recommended DE artifacts/work products that may be used as base measures of DE metrics are included in Appendix A. Recommended DE artifacts/work products that may be used as base measures of DE metrics are included in Appendix B.

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

Doc.	Excerpts	Revision
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 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.	embedded Insert: including the testing and delivery schedules of MVCRs and
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.	collection Add: , including collection of DE metrics of schedule progress towards the 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 authoritative source of truth (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 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.	**progress,** Should be: ***schedule progress,***
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.	(3) …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.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,
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**.**	deliverables Insert: that report schedule progress and product quality (functional completeness)
SEP 3.2	Engineering Resources and Cost/Schedule Reporting – List and summarize the program oversight and management systems that integrate cost, schedule, and technical performance goals, metrics, and resources.	metrics, Insert: including DE metrics, Add: Exchange of information should take place via model exchanges and automated transformations.
SEP 3.6	**Technical Performance Measures and Metrics** – Summarize the program's strategy for selecting the set of measures for tracking and reporting the maturation of system development, design, and production in terms of progress against established plans. The measures should be specific, measurable, achievable, relevant, and time-bound — sufficient to provide insight into the technical progress and risk of the program **A set of technical performance measures (TPMs), rationale for tracking, intermediate goals, and the plan to achieve them with as-of dates (to provide quantitative insight into requirements stability and specification compliance). Examples include TPMs…and integration to assess "performance to plan." (See example in Table 3.6-1.)** • Whether there are any contractual provisions related to meeting TPM goals or objectives. • Description of the traceability between Key Performance Parameters (KPPs), Key System	Add bullets: ○ For programs using the embedded software path, including CID, describe how test and integration, including test and integration of MVCRs, will be aligned with the testing and delivery schedules of the overarching system in which the software is embedded, including aligning resources and criteria for transitioning from

	Attributes (KSAs), key technical risks and identified TPMs, or other measures. ○ Identify software measures for software technical performance, process, progress, and quality.	development to test and operational environments. ○ Describe how DE schedule and technical performance measures will be the ASOT for "Performance to plan"
SEP 4.3	**Requirements Development and Change Process** • **Analysis and Decomposition** – How are top-level requirements (i.e., from Analysis of Alternatives (AoA), KPPs, KSAs, statutory, regulatory, certification, safety, software, hardware, etc.) traced from the source JCIDS documents down to configuration item (CI) build-to specifications and verification plans? Identify the tool (s) the program plans to use (or continues to use) for requirements traceability in Tools Table 4.7-1.	○ Add bullet: Describe how the DE artifacts are used as the ASOT
SEP 4.5	**Configuration and Change Management** **Technical Baseline Artifacts** – For each baseline established at a technical review, list and describe the planned or established artifacts. Typically, at a minimum, describe the artifacts of the functional, allocated, and product baseline and when each technical baseline is established and verified. ○ SFR = Functional Baseline = Artifacts containing the system's performance (functional, interoperability, and interface characteristics) and the verification required to demonstrate the achievement of those specified characteristics. ○ PDR = Allocated Baseline = Artifacts containing the functional and interface characteristics for all system elements (allocated and derived from the higher-level product structure hierarchy) and the verification required to demonstrate achievement of those specified characteristics. ○ CDR = initial Product Baseline = Artifacts containing necessary physical (form, fit, and function) characteristics and selected functional characteristics designated for production acceptance testing and production test requirements, including "build-to" specifications for hardware (product, process, material specifications, engineering drawings, and other	Add bullet: ○ MVP = Subset of initial Product Baseline ○ MVCR = Subset of initial Product Baseline

		related data) and software (software module design - "code-to" specifications).	

Appendix A ASOT for Selecting DE Metrics and Artifacts

ASOT for Selecting DE Metrics and 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.
SELI	• Requirements Validation Trends • Requirements Verification Trends • 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.
SEP	Programs require offerors to provide a tight ***linkage*** across the Integrated Master Plan, ***Integrated Master Schedule***, ***risk mitigation***, ***WBS***, and ***cost*** in their proposals and with the EVMS when implemented.
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 Recommended DE artifacts/work products

PB-EV Typical SE Work Products/Artifacts:

PB-EV Table E-1: Typical SE 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 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

PB-EV Table E-1: Typical SE Work Products/Artifacts in CMMI	
CMMI Process Area	**Typical Work Products/Artifacts**
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