Mission Assurance-Driven Processes for Software-Intensive Ground Systems

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Mission Assurance: National Security Space (NSS) Definitions*

- Mission Success
  - The acquisition and operations of systems that meet specified requirements and user expectations in terms of end-to-end operational effectiveness, operability, and supportability

- Mission Assurance
  - The disciplined application of engineering, acquisition, and management principles, processes, and standards to achieve mission success

The Mission Assurance Problem for Software-Intensive Systems

- NSS system acquisition failures attributable to software continue to mount, especially for the large, software-intensive ground systems
  - Performance deficiencies
  - Extensive software defects
  - Large, unanticipated cost and schedule overruns
- These failures contribute to a lack of mission success for these critical national security programs
- However, many of the development contractors for these space systems advertise high maturity levels
  - Levels 3, 4 and 5 when appraised against the Capability Maturity Model® Integration℠ (CMMI®)
Process Improvement Using the CMMI®

• The CMMI® is a generic model, designed to be useful for process improvement in all product domains and for multiple disciplines (e.g., systems engineering, software engineering)

• Therefore, the CMMI® provides great latitude in how its expected practices can be implemented to meet its stated goals

• In Levels 4 and 5, process improvement is based on “quality and process performance objectives”*, which are driven by the organization’s business objectives

* “Capability Maturity Model® Integration (CMMI®), Version 1.1 (CMMI-SE/SW/IPPD/SS, V1.1), Staged Representation, Software Engineering Institute (CMU/SEI-2002-TR-012), March 2002. For example, see pp. 27, 482, 486, 496, and 524.
CMMI® Process Areas Needed for Mission Assurance for Software-Intensive Systems

• The principal CMMI® process areas (PAs) needed for mission assurance consist of the following Level 2 and 3 PAs:
  ❖ Engineering
    – Requirements Management, Requirements Development, Technical Solution, Product Integration, Verification, Validation
  ❖ Support
    – Configuration Management, Product and Process Quality Assurance
  ❖ Project Management
    – Risk Management, Integrated Supplier Management

• However, mission assurance goes well beyond the CMMI® expected practices in these PAs!
  ❖ Processes also need to be effective in producing high quality products that will not require significant downstream rework

• CMMI® Level 4 and 5 process areas are not required to achieve mission success
  ❖ Level 4 and 5 can certainly help, but only if the organization’s “quality and process-performance objectives” are targeted to mission assurance
Ensuring High Mission Assurance Processes

Question: How can you ensure that high mission assurance processes are used to develop your software-intensive ground system?

Answer: Use a robust software development standard!

- For developers, this means establishing processes that go beyond the minimum requirements of the CMMI®
  - Mission assurance-driven processes
  - Not just mature processes (i.e., institutionalized, predictable) based on CMMI® expected practices
- For the government, this means making a robust software standard contractually compliant
- The CMMI® is NOT a standard!
The Software Development Standard for Space Systems (SDSSS)

- The military standard for software development (MIL-STD-498) has now been updated to include explicit requirements for high mission assurance processes
  - Part of the SMC/NRO Mission Assurance Improvement Task Force (MAITF) effort
- The standard is now being applied on new SMC and NRO contracts and is approved for public release
- Don’t let the title be misleading!
  - The standard applies to ground software development as well as onboard software development
  - The standard is not space-specific—it applies to any software development effort where mission assurance is a concern
Mission Assurance-Driven Processes

• This presentation will focus on two categories of processes critical to mission success

1. Testing* Activities
   – Software unit testing
   – Software integration testing, including
     ➢ Software unit integration testing
     ➢ Software/hardware integration testing
     ➢ Both within and across software items
   – Software qualification testing

2. Quality-Enhancing Activities
   – Peer reviews
   – Product evaluations

* The word “testing” in this presentation includes the use of all verification methods (I, A, D, T)
Software Unit Testing

**SDSSS**

- Unit testing required for each software unit
- Exit criteria specified for unit testing, e.g.,
  - All statements and branches
  - Error and exception handling
  - Interfaces, including boundary and limit conditions
  - Algorithms
- Regression testing of affected unit test cases required for all changes to previously tested software
- Conditions specified for unit testing of reuse software

**CMMI®**

- Unit testing **NOT** required or even expected
  - Subpractice 4 in the Technical Solution PA under the expected practice SP 3.1: “Implement the designs of the product components” states “Perform unit testing of the product component as appropriate”**
  - Subpractices are part of the informative material (not required or expected)

** All quotations from the CMMI® in this presentation are taken from the following reference:

**Software Integration Testing**

**SDSSS**

- **Software integration testing required**
  - On target hardware, under conditions as close to operations as possible
- **Exit criteria specified for software integration testing, e.g.**
  - Interfaces, including limits and boundary conditions
  - Integrated error and exception handling
  - End-to-end functional capabilities
  - Start up, termination, restart
  - Verification of software requirements allocated to the integrated units
  - Performance testing; stress testing
  - Fault detection, isolation and recovery
  - Resource utilization measurement
- **Regression testing of affected software integration test cases required for all changes to previously tested software**
- **Conditions specified for software integration testing of Commercial Off-the-Shelf (COTS) and reuse software**

**CMMI®**

- **Addressed by three expected practices in the Product Integration PA**
- **Software unit integration testing not explicitly required**
  1. SP 1.3: “Establish and maintain procedures and criteria for integration of the product components”
  2. SP 3.2: “Assemble product components according to the product integration sequence and available procedures”
  3. SP 3.3: “Evaluate assembled product components for interface compatibility”
Software Qualification Testing

SDSSS

• Software qualification testing required
  - On target hardware, under conditions as close to operations as possible
• Exit criteria specified for software qualification testing, e.g.,
  - Verification of all software requirements, software interface requirements, software specialty engineering requirements
  - Stress testing
  - Resource utilization measurement
  - Verification of all software requirements allocated to COTS and reuse (modified or unmodified) software
• Regression testing of affected software qualification test cases required for all changes to previously tested software
• People responsible for software qualification testing cannot be the developers of the software unit under test

CMMI®

• Addressed by four expected practices in the Verification PA
• Software qualification testing not explicitly required
  1. SP 1.1: “Select the work products to be verified and the verification methods that will be used for each”
  2. SP 1.3: “Establish and maintain verification procedures and criteria for the selected work products”
  3. SP 3.1: “Perform verification on the selected work products”
  4. SP 3.2: “Analyze the results of all verification activities and identify corrective action”
Peer Reviews

**SDSSS**
- Peer reviews of work products required
  - Specific requirements include
    - Identifying type of peer review
    - Identifying mandatory key reviewers
    - Ensuring entry criteria met
    - Reviewing materials by each reviewer before the meeting
    - Identifying and documenting defects and other issues
    - Recording results of peer review, including action items
    - Ensuring exit criteria met
    - Analyzing data about preparation, conduct and results of the peer reviews

**CMMI®**
- Addressed by three expected practices and one goal in the Verification PA
  - Goal: “Peer reviews are performed on selected work products”
  - Expected Practices:
    - SP2.1: “Prepare for peer reviews of selected practices”
    - SP 2.2: “Conduct peer reviews on selected work products and identify issues resulting from the peer review”
    - SP 2.3: “Analyze data about preparation, conduct and results of the peer reviews”
Software Product Evaluations

**SDSSS**

- In-progress and final software product evaluations required for all software products in the standard
- Criteria specified for each type of software product, e.g.,
  - Adequate, accurate, consistent, complete, feasible, testable, understandable
  - Meets requirements (technical and contractual)
  - Follows Software Development Plan
- Independence in software product evaluation required
  - Cannot be performed by the developers of the product

**CMMI®**

- Software product evaluations **NOT** explicitly addressed
  - The Verification PA addresses ensuring that selected work products meet their specified products
  - However, only peer reviews are required
  - All other examples of verification methods for software are types of testing (informative material)
Conclusion

High maturity level processes are **NOT** the same as high mission assurance processes!

- Mandating use of a robust software development standard will help ensure that high mission assurance processes are applied to your software-intensive ground system development
  - SDSSS is an update of MIL-STD-498 that includes mission assurance-related requirements
- Incentivizing mission success and the use of high mission assurance processes will help
  - Align the development contractor’s business objectives with the government’s business objectives
  - Ensure the development contractor’s process improvement efforts are targeted toward mission success
Backup Charts
SDSSS Exit Criteria For Unit Testing

• **Unit test cases shall fully cover correct execution of all:**
  - Statements and branches
  - Error and exception handling
  - Software unit interfaces, including limits and boundary conditions
  - Start up, termination and restart (where applicable)
  - Algorithms

• **Reuse software shall be unit tested for all:**
  - Modified units
  - Units where the track record indicates potential problems, even if the units have not been modified
  - Units performing a critical function

• **Regression testing of affected software unit test cases shall be performed after any modification to previously tested software**
SDSSS Exit Criteria For Software Unit Integration Testing

• Unit integration test cases shall cover:
  - Correct execution of all
    - Interfaces between software units, including limit and boundary conditions
    - Integrated error and exception handling across the software units under test
    - End-to-end functional capabilities through the software units under test
    - Start up, termination and restart (where applicable)
  - Verification of all software requirements allocated to the units under test
  - Performance testing, including operational input and output data rates and timing and accuracy requirements
  - Stress testing, including worst-case scenario(s)
  - Fault detection, isolation, and recovery handling (e.g., fault tolerance, fail over, data capture and reporting)
  - Resource utilization measurement (e.g., CPU, memory, storage, bandwidth)
SDSSS Exit Criteria For Software Unit Integration Testing (Cont.)

- Wherever possible, software unit integration testing shall be performed on the target hardware in a configuration as close as possible to the operational configuration.
- All COTS and reuse software, including both modified and unmodified reuse, shall undergo software unit integration testing.
- Regression testing of affected software unit integration test cases shall be performed after any modification to previously tested software.
SDSSS Exit Criteria For SW/HW Integration Testing

• SW/HW integration test cases shall fully address:
  ❖ Correct execution of all
    – Software-to-software and software-to-hardware interfaces among the hardware and software items under test, including limit and boundary conditions
    – Integrated error and exception handling across the hardware and software items under test
    – End-to-end functional capabilities through the software units under test
    – Start up, termination and restart (where applicable)
  ❖ Verification of all software and higher level requirements allocated to the software and hardware items under test
  ❖ Performance testing, including operational input and output data rates and timing and accuracy requirements
  ❖ Stress testing, including worst-case scenario(s)
  ❖ Fault detection, isolation, and recovery handling (e.g., fault tolerance, fail over, data capture and reporting)
  ❖ Resource utilization measurement (e.g. CPU, memory, storage, bandwidth)
SDSSS Exit Criteria For SW/HW Integration Testing (Cont.)

- Wherever possible, SW/HW integration testing shall be performed using target hardware that is as close as possible to the operational target hardware and is in a configuration as close as possible to the operational configuration.

- All COTS and reuse software, including both modified and unmodified reuse, shall undergo SW/HW integration testing.

- Regression testing of affected SW/HW integration test cases shall be performed after any modification to previously tested software.
SDSSS Exit Criteria For Software Qualification Testing

- Software qualification test cases shall fully address:
  - Verification of all software requirements under conditions as close as possible to those that the software will encounter in the operational environment
    - e.g., operational data constants, operational input and output data rates, operational scenarios, target hardware configurations
  - Verification of all software interface requirements, using the actual interfaces wherever possible or high fidelity simulation of the interfaces where not possible
  - Verification of all software specialty engineering requirements
    - e.g., supportability, testability, dependability/reliability/maintainability/availability, safety, security, and human systems integration, as applicable
    - Including, in particular, verification of software reliability requirements and fault detection, isolation, and recovery requirements
  - Stress testing, including worst-case scenario(s)
  - Resource utilization measurement (e.g., CPU, memory, storage, bandwidth)
SDSSS Exit Criteria For Software Qualification Testing (Cont.)

- All software requirements shall be verified by software qualification testing whether they are satisfied by COTS, reuse (modified or unmodified) or newly developed software.
- Regression testing of affected software qualification test cases shall be performed after any modification to previously tested software.
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<th>Acronym</th>
<th>Definition</th>
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<td>CMMI®</td>
<td>Capability Maturity Model® IntegrationSM</td>
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<tr>
<td>CMU</td>
<td>Carnegie Mellon University</td>
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<td>COTS</td>
<td>Commercial Off-the-Shelf</td>
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<td>CPU</td>
<td>Central Processing Unit</td>
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<td>GSAW</td>
<td>Ground System Architecture Workshop</td>
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<td>HW</td>
<td>Hardware</td>
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<td>I, A, D, T</td>
<td>Inspection, Analysis, Demonstration and Test</td>
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<td>IPPD</td>
<td>Integrated Product and Process Development</td>
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<td>MAITF</td>
<td>Mission Assurance Improvement Task Force</td>
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<td>MIL</td>
<td>Military</td>
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<td>NRO</td>
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<td>NSS</td>
<td>National Security Space</td>
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<td>Acronym</td>
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<td>SDSSS</td>
<td>Software Development Standard for Space Systems</td>
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<td>SE</td>
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<td>Space and Missile Systems Center</td>
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<td>SP</td>
<td>Specific Practice</td>
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