Is the CMMI\textsuperscript{1} of Value for Flight Software?

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\textsuperscript{1} Capability Maturity Model\textsuperscript{®} Integration
Foreword

- My viewpoint is that of a flight software developer
  - Not mission assurance
  - I am NOT a Lead Appraiser
- This presentation is my personal assessment
  - The opinions expressed herein do not necessarily represent the organizational viewpoint of JHU/APL.

Sources of information for this presentation

- CMMI appraisal team participation
  - Roughly 200 hours over a period of 14 months
  - 3-day training course required for formal appraisers
  - Capability Maturity Model Integration for Development (CMMI-DEV) version 1.2
    - Version 1.3 was released October 28, 2010
- Supplier agreement management
  - Oversight of many instrument FSW teams
- Experience on RBSP, STEREO, SOFIA, and other projects
“Improvement efforts are an organization’s response to pain. Determine where your organization is experiencing pain—missed deadlines, cost overruns, customer complaints, lost business, and staff turnover are just some examples—and you will likely find a fruitful area for process improvement.”

- Bill Smith, Leading Edge Process Consultants

- How FSW developers experience pain:
  - **Schedule:** lost weekends, late nights, cancelled vacations, stress illnesses, etc.
  - **Functionality:** requirements creep, redesign, late defects, spacecraft anomalies
  - **Budget:** inadequate toolsets, inadequate staffing (see schedule), layoffs
CMMI Model vs. CMMI Appraisal

- Implementing and supporting CMMI Model
  - Organizational goal:
    - Fewer missed deadlines, blown budgets, and failures
  - Likely FSW consequence:
    - Fewer “death march” projects
  - Burden on FSW:
    - Ongoing
    - Time spent doing “less fun stuff”

- Obtaining a formal CMMI appraisal
  - Organizational goal:
    - Better ability to compete against un-appraised shops
  - Likely FSW consequence:
    - Increased customer / sponsor confidence
  - Burden on FSW:
    - Episodic
    - Time spent with / on the appraisal team
What is CMMI?

- Capability Maturity Model Integration

- CMMI is a model for software process improvement
  - Goals and practices
  - Maintenance activities
  - Roadmaps and interconnections

- Five-level description of how “best practices” are integrated into an organization

- Started out as an Air Force study of software management
  - Attempt to put software under statistical quality control

- Evolved tremendously since 1989
  - Added more elements to cover acquisition and services
  - Developed the formal appraisal process (SCAMPI)

- Created at and owned by the Software Engineering Institute of Carnegie Mellon University
Maturity Level 1
No Effective Management

7 Key process areas (KPAs) in Level 2
 Requirements Management (REQM)
 Project Planning (PP)
 Project Monitoring and Control (PMC)
 Supplier Agreement Management (SAM)
 Measurement and Analysis (MA)
 Process and Product Quality Assurance (PPQA)
 Configuration Management (CM)

11 KPAs added for Level 3
 Requirements Definition (RD)
 Technical Solution (TS)
 Product Integration (PI)
 Verification (VER)
 Validation (VAL)
 Organizational Process Definition (OPD)
 Organizational Process Focus (OPF)
 Organizational Training (OT)
 Integrated Project Management (IPM)
 Risk Management (RSKM)
 Decision Analysis and Resolution (DAR)

2 KPAs added for Level 4
 Organizational Process Performance (OPP)
 Quantitative Project Management (QPM)

2 KPAs added for Level 5
 Causal Analysis and Resolution (CAR)
 Organizational Innovation and Deployment

- Level 5: Optimizing
  - Continuous improvement
- Level 4: Managed
  - Predictable
- Level 3: Defined
  - Standard, consistent
- Level 2: Repeatable
  - Intuitive
- Level 1: Initial
  - Ad hoc, chaotic
Maturity Level 2
Basic Management and Quality Assurance

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Maturity Level 3: Management, Quality Assurance, and Engineering

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Maturity Levels 4 and 5: Closed Loop Software Process Control

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Specific Goals and Practices
Example: Project Planning (“PP”)

SG 1 Establish Estimates
   SP 1.1  Estimate the Scope of the Project
   SP 1.2  Establish Estimates of Work Product and Task Attributes
   SP 1.3  Define Project Lifecycle
   SP 1.4  Determine Estimates of Effort and Cost

SG 2 Develop a Project Plan
   SP 2.1  Establish the Budget and Schedule
   SP 2.2  Identify Project Risks
   SP 2.3  Plan for Data Management
   SP 2.4  Plan for Project Resources
   SP 2.5  Plan for Needed Knowledge and Skills
   SP 2.6  Plan Stakeholder Involvement
   SP 2.7  Establish the Project Plan

SG 3 Obtain Commitment to the Plan
   SP 3.1  Review Plans That Affect the Project
   SP 3.2  Reconcile Work and Resource Levels
   SP 3.3  Obtain Plan Commitment
How Does CMMI Process Improvement Affect Flight Software Developers?

- Emphasis on good management practices
  - Project planning, project monitoring and control
  - Less reliance on individual heroics
  - Fewer “death marches”
- Emphasis on “not just this time, but next time”
  - Measure and analyze so you don’t underestimate software time and effort
  - Document “how you do what you do” (process documentation)
- Coding & testing are a “smaller fraction of the pie”
  - More effort spent in software project management, requirements management
  - More involvement with system engineering, project management, mission assurance
Are the CMMI Practices Themselves Painful?

- Few FSW developers would call (most of) the CMMI practices “fun”.
  - But developers in CMMI Level 2 (“Repeatable”) organizations can (usually) keep normal hours (if they want to).
  - Developers in CMMI Level 3 (“Defined”) organizations can collaborate much more effectively.

- Organizations that incorporate CMMI practices are likely to be less painful to work for.
What is a Formal CMMI Appraisal?

- **Standard CMMI® Appraisal Method for Process Improvement (SCAMPI)**
  - Gather and present objective evidence (paper or electronic documents) for each process
  - Usually 2 pieces of evidence
    - Process (quality system) document = “This is what we do and how”
    - Product (project) document = “This is what we did”
- Appraisers require SEI-certified training
  - 3-day “Introduction to CMMI”
  - 2-day “CMMI auditor”
- **Class C Gap Assessment**: One project, 75% complete
- **Class B Gap Assessment**: 3 projects, 90% complete
- **Class A Appraisal**: 3 projects, 100% complete
  - Outside appraiser and on-site self-appraisers perform Class A Appraisal
  - Organization gets listed on CMU/SEI Website after outside appraiser reviews

Published Appraisal Results
Boxes to be Filled In
Specific Goals and Practices

|       | CAR | CM | D | AR | IP | M | A | D | O | ID | P | D | O | PD | O | P | F | O | P | T | P | PI | PMC | PP | PPQA | QPM | RD | REQ | RSKM | SAM | TS | VAL | VER |
| SG 1  |     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 1.1| 5   | 2  | 3 | 3  | 2  | 5 | 3 | 3 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 4 | 3 | 2 | 3 | 2 | 3 | 3 | 3 |     |    |   |   |   |
| SP 1.2| 5   | 2  | 3 | 3  | 2  | 5 | 3 | 3 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 4 | 3 | 2 | 3 | 2 | 3 | 3 | 3 |     |    |   |   |   |
| SP 1.3| 2   | 3  | 3 | 2  | 5 | 3 | 3 | 4 | 3 | 3 | 2 | 2 | 2 | 4 | 2 | 3 | 2 | 3 | 3 |     |    |   |   |   |   |   |   |   |
| SP 1.4|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 1.5|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 1.6|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 1.7|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SG 2  |     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 2.1| 5   | 2  | 3 | 2  | 5 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 4 | 3 | 3 | 2 | 3 | 3 |     |    |   |   |   |   |   |   |   |
| SP 2.2| 5   | 2  | 3 | 2  | 5 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 4 | 3 | 3 | 2 | 3 | 3 |     |    |   |   |   |   |   |   |   |
| SP 2.3| 5   | 3  | 2 | 5  | 3 | 3 | 2 | 2 | 4 | 3 | 2 | 3 | 3 |     |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 2.4|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 2.5|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 2.6|     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
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| SG 3  |     |    |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 3.1| 2   | 3  |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SP 3.2| 2   | 3  |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
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### Boxes to be Filled In

#### Generic Goals and Practices

|-----|-----|------------------------|----------------------------|------------------------------------|----------------------------------|-----------------|------------------|---------------------|---------------|------------------------|---------------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|----------------------------------|---------------------------------|------------------------|----------------------------------|----------------------------------|---------------------------------|-------------------------------|---------------------------------|
What Support is Required for a Formal CMMI Appraisal?

- At a minimum, SCAMPI appraisal requires
  - Lead Appraiser
  - Training courses and trainer certifications
  - Software Engineering Institute appraisal registry
- Most SCAMPI efforts also require
  - Software
  - Consultants
  - Books

- JHU/APL SCAMPI in 2009-2010 used all the above
How Does a CMMI Appraisal Affect Flight Software Developers?

- Appraisal team needs active participation of at least one software engineer
  - Total effort for me was ~1 staff month
- Support for evidence gathering
  - Depends how well your material is organized
- Interviews
  - 1-2 hours for each appraisal (C, B, and A) from each project
- External appraisers, consultants, and training costs $10,000’s
  - Time and budget for appraisal should not come from your projects!
What’s Wrong with SCAMPI?

- No independence
  - Some or all appraisers are part of the organization to be appraised
  - Independent consultants and appraisers must collaborate with organization to conduct the appraisal
- SCAMPI was designed for self-appraisal, not publication
- Allows for intentional and unintentional bias
  - Organization selects which projects and which parts of the organization get appraised
  - Interviewees can be coached on how to answer questions for objective evidence scores
- CMMI process improvement can turn into a box-checking exercise
  - Is 1 document per project + 1 interview record evidence that a practice is institutionalized?
- Formal appraisal for the purpose of publication systematically over-estimates capability maturity
CMMI Use By NASA

- NASA centers have traditionally had their own standards for software engineering, e.g., JPL D-4000
  - Some centers are more mature than others
  - Some projects waive center standards
  - Center standards do not guarantee contractor performance
- CMMI appraisal was added to NPR 7150.2A NASA Software Engineering Requirements in 2009
  - Provides a uniform model, not center-specific processes
  - Assumes that CMMI Level 2 cannot be achieved without some control over software management and engineering
Is CMMI Appraisal Required? (NASA Says, “Yes”)

NASA Procedural Requirement (NPR) 7150.2A NASA Software Engineering Requirements

2.5.1 [SWE-032] The project shall ensure that software is acquired, developed, and maintained by an organization with a non-expired Capability Maturity Model Integration® for Development (CMMI-DEV) rating as measured by a Software Engineering Institute (SEI) authorized or certified lead appraiser as follows:

For Class A software:

CMMI-DEV Maturity Level 3 Rating or higher for software, or CMMI-DEV Capability Level 2 Rating or higher for software in the following process areas:

- a. Requirements Management.
- b. Configuration Management.
- d. Measurement and Analysis.
- e. Project Planning.
- f. Project Monitoring and Control.
- g. Supplier Agreement Management (if applicable).

For Class B software:

The required CMMI-DEV Maturity Level for Class C software will be defined per Center or project requirements.
Is CMMI Appraisal Required? (US Defense Department Said, “Yes”)

- Interim Defense Acquisition Guidebook (October 30, 2002)
  “Contractors performing software development or upgrade(s) for use in an ACAT I or ACAT IA program shall undergo an evaluation, using either the tools developed by the Software Engineering Institute (SEI), or those approved by both the DoD Components and the Deputy Director, Software Intensive Systems. **At a minimum, full compliance with SEI Capability Maturity Model Level 3, or its equivalent in an approved evaluation tool, is the Department's goal.**”
Is CMMI Appraisal Required? (US Defense Department Now Says, “No”)

Defense Acquisition Guidebook 4.2.2 The Contractor’s Systems Engineering Process (modified January 7, 2010)

Organizations use different standards and capability models and their accompanying assessment methods to establish the initial capability of their systems engineering processes and then to improve those processes. When contractors use the Capability Maturity Model Integration (CMMI) models, they often quote a CMMI "level" rating that is the result of an appraisal. DoD does not place significant emphasis on capability level or maturity level ratings, but rather promotes CMMI as a tool for internal process improvement. This lack of emphasis on ratings is prudent in the light of findings that not all suppliers are exhibiting behavior consistent with their attained CMMI maturity level rating. The CMMI models provide a set of best practices to be employed by the supplier and the acquirer. It is essential that DoD and industry use these practices in the right manner and with the appropriate measure. Detailed guidance can be found in "Understanding and Leveraging a Contractor's CMMI Efforts: A Guidebook for Acquirers."
Other Models for Software Engineering and Project Management

- ISO 12207 Standard for Software Lifecycle Processes
- NPR 7150.2A NASA Software Engineering Standards
- AS9100 Quality Management Systems - Requirements for Aviation, Space and Defense Organizations from International Aerospace Quality Group
- International Council on Systems Engineering (INCOSE) Systems Engineering Handbook and Certification
- Project Management Body of Knowledge (PMBOK)
How Should NASA Assure Software Engineering Process Control?

- CMMI appraisals via SCAMPI A are less than ideal
  - Expensive for FSW organizations
  - Not necessarily indicative of maturity
- Software-producing organizations are already hosting multiple external auditors
  - NASA Contractor Assurance Services (NCAS) Audits
  - AS9100 certification
- NASA should remove the emphasis on formal CMMI appraisals from NPR 7150.2A
- NASA should use a variety of methods (CMMI Supplier Agreement Management, AS9100, INCOSE, PMBOK) for supplier appraisal.
Synopsis

- Distinguish between formal appraisal and internal process improvement and self-appraisal.
- The CMMI model— the practices and how they are organized— is useful for process improvement.
  - CMMI documentation contains lots of guidance on how to improve the software process.
  - CMMI begins by attacking clueless management.
- An informal appraisal performed for the purpose of process improvement is helpful even for relatively mature organizations.
- Formal appraisal gives organizations a competitive edge in bidding.
  - Published at [http://sas.sei.cmu.edu/pars/pars.aspx](http://sas.sei.cmu.edu/pars/pars.aspx)
  - Almost essential if your FSW organization will be developing for NASA due to NPR 7150.2A
  - US DoD has decreased its emphasis on formal appraisal.
- A formal appraisal done for the purpose of publishing the result will probably over-rate your organization’s true capability maturity.
Backup Materials
A Real Example
Small FSW Developer For an Instrument

Developer’s View
- Tightly integrated with hardware developers and instrument scientists
- Use “Scrum” methodology for development
  - Parse requirements as “stories”
  - Divide work into “sprints”
- Plan, monitor and control software development using Excel spreadsheets
- Estimate and track effort in staff days, one sheet per “sprint”
- Developer is confident he knows what he’s doing

View from Supplier Agreement Management
- Good collaboration with stakeholders
- BUT:
  - No one had actually read the book or been trained in Scrum methodology
  - Terminology was meaningless
  - No basis for estimates of effort
  - Effort planning / tracking was not tied to calendar dates
  - Scheduled milestones never defined
  - No one (including the developer) knew when he’d be done
Example Results from JHU/APL SCAMPI

- SCAMPI C Findings
  - Some key process areas were not mentioned in the quality policies
  - One key process area had no defined standard methodology
    - But the team found evidence for the practices
  - Process with no owner
  - Practice lacking objective evidence

- Problems NOT found by SCAMPI
  - Data from older projects no longer findable
  - No evidence that “read-and-certify” training was effective

- All problems were found during SCAMPI C (first assessment)
  - Value of SCAMPI A was the ability to publish the result.
Some FSW Providers with CMMI Published Appraisal Results

- Ball Aerospace & Technologies Corp.
- Boeing (KSC)
- Computer Sciences Corporation (Air, Missile, and National Defense (AMND) Development Engineering (DE))
- Draper Laboratory
- EADS Astrium
- Honeywell Aerospace
- ITT Corporation (Space System Division)
- Jet Propulsion Laboratory (ESD Mission Software Development)
- Johns Hopkins University Applied Physics Laboratory (Space Department)
- Lockheed Martin Corporation (Space Systems)
- Northrop Grumman Corporation (Aerospace Systems, Space Systems Division)
- Raytheon (Space & Airborne Systems)
- Science Applications International Corporation (Space Geospatial Intelligence)
- SouthWest Research Institute (Division 10)
- Thales Alenia Space
- United Space Alliance (Flight Software Element (FSWE))
- Wind River Systems, Inc. (Solutions & Services)

- National Aeronautics and Space Administration
  - NASA Ames Research Center: Intelligent Systems Division
  - Glenn Research Center - Software Engineering Branch (DPS)
  - NASA GSFC Class A and Class B Projects
  - NASA JSC Spacecraft Software Engineering
  - Kennedy Space Center Command, Control, and Communications Launch Control System Software Development
  - Marshall Space Flight Center - Avionics and Software Ground Systems Test Branch (ES53)
  - Marshall Space Flight Center - Software Systems Engineering and Software Development Branches (ES51-ES52)

- US Navy (Space and Naval Warfare Systems Center)
  - New Orleans
  - Pacific
  - Atlantic