Software Sustainment Performance Measures – A Tutorial on Identifying and Implementing Effective Measures for Today’s Weapons Systems

2018 DoD Maintenance Symposium

December 17, 2018

Michael H. McLendon
Dr. Christopher L. Miller
The SEI is a DoD Federally Funded Research and Development Center (FFRDC)

• Established in 1984 at Carnegie Mellon University
• Only DoD R&D center focused on SW engineering and cybersecurity
• ~615 employees (ft + pt), of which about 70% are engaged in technical work
• Initiated CERT cybersecurity program in 1988
• Offices in Pittsburgh and DC, LA, Boston, San Antonio, Pax River… facilities
• About $150M in funding (~$20M DoD R&D)
We Serve a Broad Spectrum of Stakeholders

• We deliver technical analysis and solutions to a broad range of government customers
  - DoD
  - Intelligence Community
  - Federal agencies (DHS, VA, DOE, DOC, FDA, FAA…)
• States and local government offices and municipalities
• Key industries and organizations with the potential to advance software engineering and related disciplines
• Engagement and collaboration with other FFRDCs, academics, and research organizations
Outline

• Learning Objective
  • DoD Software (SW) Sustainment Study Overview
  • Establishing a Successful Measurement Capability
  • Identifying, Defining, and Implementing Sw Sustainment Performance Measures
  • Key Take-Aways
Tutorial Motivation and Objectives

**Motivation:**

- As software plays an ever-increasing role in enabling weapon systems, and consuming precious resources, the need for objective management and insight is essential
- Too often there is a lack of sufficient quantitative insight into software sustainment activities and performance
- Utilizing a planning measurement process, the Sw Sustainment Ecosystem, and common software sustainment information needs a candidate set of measures can be identified

**Objectives:**

- This tutorial provides attendees with:
  - Insight into the state of the practice for measuring software sustainment and maintenance across the DoD
  - How to identify, define and implement performance measures
  - Examples of Sw Sustainment performance measures at the Project, Organizational and Enterprise levels
Bottom Line Upfront - There is No Silver Bullet

- Sw sustainment demand will continue to grow as % and $ of DoD depot workload...creating greater readiness, affordability challenges
- There are NOT 3-5 metrics that can be applied to every sw sustainment activity
- Useful metrics are:
  - A by-product of an effective measurement process
  - Provide insight to the most important decisions pertaining to sw sustainment
  - Continually refined as the sw baseline and related sw sustainment activities evolve over time
- Even the best performance measures only provide objective insight; decisions pertaining to workload, staffing, funding, technology insertion and refresh cycles remain in the hands of leadership
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Sw Sustainment (SwS) – Our Perspective

“Orchestrating the processes, practices, technical resources, information, and workforce competencies for systems and software engineering…

…to enable systems to continue mission operations and also to be enhanced to meet evolving threat and capability needs.”

SwS is about engineering...every time you touch...you go thought the systems and SW engineering development life cycle
SwS Study Phase I

Emphasized the need for the DoD to have visibility of its software portfolio in order to inform policy and resource allocation decisions.

A lack of insight at the Service and DoD enterprise levels of the size, complexity, and characteristics of the DoD software inventory, which hinders DoD’s:

- Ability to craft policies
- Make investments to optimize the use of the DoD’s software sustainment capacity
- Achieve greater productivity at more affordable costs in the face of ever-increasing demands and a dynamic cyber environment.

**Phase I Recommendation**

Create an enterprise software sustainment performance measurement system to enable consistent visibility and evaluation of the cost, quality, and productivity of DoD software sustainment industrial base.
SwS Study Phase II

The SEI Phase II Study measurement task focused on two areas:

• Investigating the measurement of the how the Services measure, calculate and report software in support of Title 10, United States Code, Section 2464, Core logistics capabilities.
• Definition of software maintenance
• Varying measurement methods
• Identifying existing SwS performance measurement approaches, measures, and metrics in use in the DoD’s organic SwE sustainment organizations.
• Services and Programs use these measures with varying consistency and sophistication. Measures most often tied to another initiate (e.g., CMMI); measuring project magnitude (in terms of team size, cost, and end size of the software product), duration, and product quality.

*Phase II SwS fact-finding did not identify any performance measures at any level that are unique to the SwS environment.*
SwS Study Phase III

SwS measurement is implemented during initial software development, and not revisited to address the SwS ecosystem, and not refined/adapted to address sustainment information needs, decisions, or issues.

The focus of measurement tends to be financial in nature (e.g., budget, cost, FTEs, etc.) and lacks granularity to provide visibility into individual SwS tasks and activities

- CAPE initiated collection of historical SwS project data via DID 3026-2 Maintenance Software Resources Data Report

Lack of standardized data across SwS projects prevents the SwS community from being able to answer some basic questions (e.g., How many SLOC does DoD maintain? How many people in the DoD workforce perform SwS?).
SwS Study Phase III

No measures found that address the enterprise view of SwS

Sporadically encountered organizational level measures in use to provide insight related to Depot (or SEC) performance, organizational skill sets, and accessing process performance. Most focus on financial viability.

Individual SwS measures on projects varied. No SwS-specific measures found to estimate SwS product size or magnitude of work. SwS Workforce estimated as level of effort.

Did NOT find any evidence of institutionalized application of measures to routinely provide SwS insights, for example:

- Total SLOC maintained by the DoD
- Number of people sustaining software (both organic and supplemental)
- Operating and support costs across various divisions, programs, and depots
- Capability and gap assessments based on delivery, cost and quality (e.g., amount of functionality delivered by release)
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ISO/IEC/IEEE 15939:2017
Systems and software engineering -- Measurement process

Provides an elaboration of the measurement process from ISO/IEC 15288 and ISO/IEC 12207

The measurement process is applicable to system and software engineering and management disciplines.

The process is described through a model that defines the activities of the measurement process that are required to adequately specify what measurement information is required, how the measures and analysis results are to be applied, and how to determine if the analysis results are valid. The measurement process is flexible, tailorable, and adaptable to the needs of different users.
ISO/IEC/IEEE 15939:2017
Measurement process
Measurement 101

Measurement principles

• An effective measurement capability comes from a process
  • NOT a pick list of metrics
• Data collection without analysis provides little value
• Measures need to be derived from stakeholder information needs

A robust measurement program will:

• Support technical and managerial decisions; and predict future performance
• Enable objective communication of performance and outcomes
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Can measures be applied?

Paulk et. al., *The Capability Maturity Model: Guidelines for improving the Software Process*
SwS Technical and Management Processes and Activities

- System(s) Engineering
- Interface Control
- Hardware Engineering
- System Upgrades & Enhancements
- Software Dev. Environment & Infrastructure Management

- Requirements Analysis
- Architecture and Design
- Code and Unit Test
- Integration and Test
- Configuration Management
- Sw Quality Assurance

- Depot Sustainment Policies, Processes & Practices
- Weapons Portfolio Decision Analysis
- Sw Project Planning and Control
- Cyber Response Team
- Certification and Accreditation
- Release Roll-out
- Training
- Help Desk (User Feedback)
SwS Perspectives

Enterprise Level
- DoD
- Service Component / PEO
- Systems of Systems / IoT / Mission Capability

Organization Level
- Software Engineering Center (SEC)
- Program
- System
- Build / Release / Iteration

Project Level
- Team
- SwS WBS
- Workforce / Skill Sets
- Operational Sw Baseline

Perspective is everything in terms of assessing the value of metrics
## Project-level Candidate Measures

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Questions/Information</th>
<th>Candidate Measures/Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational Software Baseline</strong></td>
<td>• How big is the operation baseline? SLOC?</td>
<td>• KSLOC, Computer Software Configuration Items (CSCIs), number of weapon system platforms it runs on</td>
</tr>
<tr>
<td></td>
<td>• What are the quality issues in the software baseline?</td>
<td>• Defects (open, discovered)</td>
</tr>
<tr>
<td><strong>SwS WBS</strong></td>
<td>• What activities are included in SwS?</td>
<td>• SwS WBS elements</td>
</tr>
<tr>
<td><strong>Team</strong></td>
<td>• Staff (staff, open billets)</td>
<td>• Attrition/Turnover</td>
</tr>
<tr>
<td></td>
<td>• What is the staff make-up?</td>
<td>• Percentage organic to contractor</td>
</tr>
<tr>
<td><strong>Workforce/Skill Sets</strong></td>
<td>• What software skills are critical to this project?</td>
<td>• Programming language, integrated development environment (IDE), modeling, architecting, design experience</td>
</tr>
<tr>
<td></td>
<td>• What domain or system experience is critical to sustain the software?</td>
<td>• Years of experience in domain</td>
</tr>
<tr>
<td><strong>Build/Release/Iteration</strong></td>
<td>• How big is the release? What are the appropriate measures of size?</td>
<td>• Size: SLOC, CSCIs</td>
</tr>
<tr>
<td></td>
<td>• How much do I need to budget for? Do I have the staff to get it done?</td>
<td>• Estimated cost, forecasted effort and staffing profile</td>
</tr>
<tr>
<td></td>
<td>• What is the release delivery date? Is the project going to delivery on end? Is our team’s velocity consistent with industry (expectations)?</td>
<td>• Start date, release date</td>
</tr>
<tr>
<td></td>
<td>• Are there minimal defects?</td>
<td>• Defects (forecasted, opened, burn down rate)</td>
</tr>
</tbody>
</table>
Organization-level Candidate Measures

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Questions/Information</th>
<th>Candidate Measures/Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program</td>
<td>• How many SwS projects are in the portfolio?</td>
<td>• Number of projects</td>
</tr>
<tr>
<td></td>
<td>• How much are we spending on SwS across each program and in total for the organization?</td>
<td>• EVMS</td>
</tr>
<tr>
<td></td>
<td>• What is the forecast/budget for the next remaining years of life?</td>
<td>• Annual budgeting</td>
</tr>
<tr>
<td>System</td>
<td>• How many software baselines are maintained?</td>
<td>• Number of unique software baselines sustained</td>
</tr>
<tr>
<td></td>
<td>• Which WBS activities are consuming the most budget? Most variable?</td>
<td>• Costs by SwS WBS activity by Program</td>
</tr>
<tr>
<td></td>
<td>• Which components of the software baseline require updates or patching the most?</td>
<td>• Critical technology refresh cycle (stability)</td>
</tr>
<tr>
<td></td>
<td>• Number of unique software baselines sustained</td>
<td>• Number of vendor updates</td>
</tr>
<tr>
<td>Software Engineering Center</td>
<td>• Is staff turnover an issue?</td>
<td>• Attrition/Overlap</td>
</tr>
<tr>
<td></td>
<td>• How many SwS job openings are there currently?</td>
<td>• Number of staff (staff, open billets)</td>
</tr>
<tr>
<td></td>
<td>• How does our organization perform compared to industry?</td>
<td>• Process performance</td>
</tr>
<tr>
<td></td>
<td>• What does is the cost of a SwS change?</td>
<td>• Estimation algorithms and historical project data</td>
</tr>
</tbody>
</table>

Information Need

- Information Product (Interpretation)
- Indicator (Analysis)
- Derived Measure(s) (Function)
- Base Measure(s) (Method)
- Attribute(s) (Entity)
Enterprise-level Candidate Measures

<table>
<thead>
<tr>
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<th>Candidate Measures/Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systems of Systems/IoT/Mission</strong></td>
<td>• How much mission capability is dependent on software?</td>
<td>• Software-enabled systems mapped to Mission capabilities</td>
</tr>
<tr>
<td><strong>Capabilities</strong></td>
<td>• How resilient is the end-to-end SoS?</td>
<td>• Technical performance measures (TPMs)</td>
</tr>
<tr>
<td><strong>Service Component/PEO</strong></td>
<td>• How much software is the Service responsible to sustain?</td>
<td>• SLOC, CSCIs, unique software baselines, systems</td>
</tr>
<tr>
<td></td>
<td>• How much does it cost the Service to sustain?</td>
<td>• Number of SwS staff (total required, organic, contractor) and open billets per location</td>
</tr>
<tr>
<td></td>
<td>• How are the sustainment organizations performing?</td>
<td>• Core system by Depot</td>
</tr>
<tr>
<td></td>
<td>• Which locations can take on additional software?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• How much of the Services’ software is organically sustained? How much is core? How</td>
<td></td>
</tr>
<tr>
<td></td>
<td>much of that is liable to move to organic sustainment in the future?</td>
<td></td>
</tr>
<tr>
<td><strong>DoD Enterprise</strong></td>
<td>• How much software does the DoD own today?</td>
<td>• SLOC, CSCIs, unique software baselines, systems</td>
</tr>
<tr>
<td></td>
<td>• How much does it cost DoD to sustain?</td>
<td>• Cost, effort, number of software sustainers</td>
</tr>
<tr>
<td></td>
<td>• How are DoD sustainment organizations performing?</td>
<td>• Number of staff identified as critically skilled’ (total required, organic, contractor)</td>
</tr>
<tr>
<td></td>
<td>• Which Services can take on additional software?</td>
<td>and open billets</td>
</tr>
<tr>
<td></td>
<td>• How much of the DoD’s software is organically sustained?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• What is the Services’ core posture? (How much risk to national security?)</td>
<td></td>
</tr>
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Information Need
- Information Product (Interpretation)
- Indicator (Analysis)
- Derived Measure(s) (Function)
- Base Measure(s) (Method)
- Attribute(s) (Entity)
Prioritization and Down-selecting

Prioritization of candidate measures

- Include all stakeholders
- Establish ranking and clarify purpose to participants (use a facilitator)
- Prioritize based on pressing issues and importance of information needs

Down-selecting prospective measures

- Level of insight provided to information needs
- Ease/difficulty of data collection and analysis
- Leverage common purpose data; minimize data collection
- Whenever possible use data that is a nature by-product of SwS activities
- Externally required data
Implementation and Training

Implementation and Infrastructure
- Establish data collection processes and infrastructure
- Pilot and test new processes and tools
- Confirm usability of new measures with intended stakeholders

Training and Rollout
- Provide training on measurement constructs, data collection, data validation, storage, analysis, and reporting procedures
- Minimize impact to operations; consider phased rollout
Seven Steps for Successful SwS Measures

1. Understand the role and nature of **software** based on the portfolio, system, components, technology in your span of control.

2. Create a performance measurement strategy to monitor and manage software and the software ecosystem (to include two aspects: as-is and acknowledging rapid evolution).

3. Identify key stakeholders (decisions)

4. Solicit information needs and decision support opportunities

5. Internal and external
   - SoS, System, software, interfaces, components

6. Identify, define, and implement performance measures

7. Refine over time!
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SW Technologies Evolve Much Faster Than Systems are Fielded…Velocity Critical to Leverage Technology
Software Drivers Not Like HW

- **Where hardware cost is driven by physical factors** (aging, weight, operating hours/cycles, etc.) creating failure…

- **Software sustainment does not scale**, driven by
  - Increasing functionality to meet new war warfighter performance needs
  - Fact-of-life changes to remain operational in the changing “netted” space
  - Technical demands of being in “all about data & information environment”
  - Resolving “technical debt” carryover from acquisition
  - Multiple configurations
  - New systems; future configurations
  - Fixed cost SW engineering & technology based SIL infrastructure
Software Vulnerabilities are Ubiquitous and Impact Mission Capability
Software and Security Failures are Expensive

Toyota reaches $1.2 billion settlement to end probe of accelerator problems

Toyota Sudden Acceleration Defect Case: $1.1 Billion Settlement

Source: The Washington Post


Average cost in a breach: US$188 per record


Source: Ponemon Institute, "2013 Cost of Data Breach Study: Global Analysis", May 2013
Increasing Complexity of Cybersecurity in an Operational Systems-of-Systems Environment

DoD must be able to operate:
- between layers
- between networks
- between domains
- between environments

Source: Kenneth R. Turner
Dep. Director, Spectrum Policy and International Engagements
DoD Chief Information Officer

UNCLASSIFIED

DoD must be able to operate
• between layers
• between networks
• between domains
• between environments
Embedded Systems Represent New Classes of Vulnerabilities

Embedded systems have different characteristics than IT systems

More and varied attack surfaces
- Sensors
- Multiple command-and-control masters
- Embedded firmware, FPGAs, ASICs
- Unique internal busses & controllers

Size, weight, power and latency demands tradeoff against defense-in-depth

Timing demands offer potential side channels
- Bit and clock cycle level operations
- Physical resources with real time sensors
- Safety-Critical Real-time OS

Confusion between failure resilience and attack
- Intermittent communications
We are Conditioned to Think About Security in an IT/Network Context…But the Reality is Different

1st line of defense in software assurance is the application (software) layer

84% of breaches exploit vulnerabilities in the application

Yet funding for IT defense vs. software assurance is 23 to 1

1. Clark, Tim, “Most Cyber Attacks Occur from This Common Vulnerability,” Forbes, 03-10-2015
There is one Characteristic of HW that has a SW Corollary: Fixing Problems Late Drives Costs, Impacts Mission Readiness

Software problems that drive costs are introduced early in the lifecycle . . .

Percentage of flaws introduced by Phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Percentage of Flaws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>70%</td>
</tr>
<tr>
<td>Strategy</td>
<td>3.5%</td>
</tr>
<tr>
<td>Acquisition</td>
<td>20%</td>
</tr>
<tr>
<td>Architecture</td>
<td>16%</td>
</tr>
<tr>
<td>Software</td>
<td>10%</td>
</tr>
<tr>
<td>Development</td>
<td>81.5%</td>
</tr>
<tr>
<td>Integration</td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
</tr>
<tr>
<td>Remediation</td>
<td></td>
</tr>
<tr>
<td>User Experience</td>
<td></td>
</tr>
</tbody>
</table>

But discovered late, they increase cost, vulnerabilities, impact schedule, and system performance

Percentage of flaws fixed by Phase
Critical to Focus Upfront ("Pay Me Now or More Later")…

1-5% of vulnerabilities due to defects; common vulnerabilities driven by coding/design defects of known types.
SwS Performance Measurement Tutorial Summary

This tutorial:

- Summarized the state of SwS performance measurement
- Proposed how the DoD should think about SwS performance measurement going forward.

DoD SwE sustainment organizations perform a critical role by continuously delivering operational capability to the warfighter. Objective measures are need to:

- Perform trades pertaining to mission capability
- Be better informed about the performance of its SwE capabilities
- Make informed policy, program, and resource allocation decisions.

The candidate measures are tools to assist in the development of local measurement activities across sustainment community stakeholders.

The most critical need is to develop a performance measurement system to enable evaluation of the DoD organic SwE sustainment enterprise.
Discussion
SEI Team Contact Information

Christopher Miller  
Senior Researcher  
Telephone: +1 703-247-1416  
Email: clmiller@sei.cmu.edu

Michael McLendon  
Associate Director, Software Solutions Division  
Telephone: +1 703-247-1389  
Email: mmclendon@sei.cmu.edu
Backups
SW Sustainment Ecosystem

- Four **infrastructure** elements: Basic, fundamental resources necessary for the sustainment activities
- Three **knowledge and expertise** elements: Skill sets, the government organic workforce, access to necessary technical information needed to deliver and deploy the capabilities for the warfighter
  - Enabling Resources/Activities
    - Facilities
    - Operational SW Deployment
    - Mgmt/Performance Measurement

"DoD Software Sustainment Study Phase I: DoD’s Software Sustainment Ecosystem." Special Report CMU/SEI-2016-SR-035.
Ecosystem Elements

**Infrastructure**
- **Systems and Software Engineering Process and Tools** – The engineering practices to be applied to plan and execute the work.
- **Enabling IT Infrastructure** – The information technology environment and assets upon which the work must be conducted.
- **Test and Evaluation (T&E)** – The mechanisms by which changes made during software sustainment are verified as ready to be rolled out to users. For DoD weapons systems, significant investments in program-specific hardware may be required.
- **Systems Integration Laboratory (SIL)** – The SIL is a specific type of T&E equipment, providing accurate analysis of the impact of changes, and is increasingly important to DoD sustainment practice.

**Knowledge and expertise**
- **Workforce (Competency and Staffing)** – The means of accessing a sufficient organic workforce with appropriate skill sets.
- **Business Model (Incentives, Workshare)** – The strategic decision regarding which parts of the work will be done by the organic workforce and which by contractors, and how the overall work is managed both technically and contractually.
- **Technical Data Rights and Licensing** – The tactical decisions governing what technical information is necessary to be accessed by the organic workforce, and the mechanisms by which they have access.

**Enabling Resources/Activities**
- **Facilities** – The physical location that meets the needs of the work (providing sufficient space, security levels, etc.).
- **Operational Software Deployment** – The mechanisms and strategy by which new versions of the software under sustainment are delivered to users.
- **Management and Performance Measurement** – The management function necessary to organize and monitor the work being conducted to ensure that it is executing as planned, and to identify any problems that need to be resolved.