Engineering Systems of Systems: An Integration Perspective

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System of Systems Engineering (SoSE) at NSWCDD

Objectives:

Discuss systems engineering practices of NSWC Dahlgren Division when carried out in the system of systems environment.

Discuss Dahlgren SoSE efforts and related system context, lessons learned, and challenges

Opinions expressed are those of the principal author, and do not reflect official policy or positions of the Navy, Navy or DoD programs of record, or NSWCDD. With grateful acknowledgement to co-authors G. Goddin, J. Heil, J. McConnell, P. Pierce, G. Rivera, S. Such for valuable discussion and perspectives on best practice and lessons learned in SoSE.

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Agenda

NSWCDD's Systems Engineering Process

NSWCDD Perspective and inputs to the OSD SoSE Guide

Case studies, Best practice, Lessons learned

- Chem-Bio Architecture Engineering
- Naval Integrated Fire Control – Counter-Air
- Combat Systems Engineering across Surface Ship Classes
- Aegis Ballistic Missile Defense
- Software Engineering
- Affordable Weapons Systems

NSWCDD Systems Engineering*

Translate needs into feasible concepts

Requirements Analysis

Systems Analysis and Control

Provide visibility to ensure product quality and conformance to project plan; ensures best practice

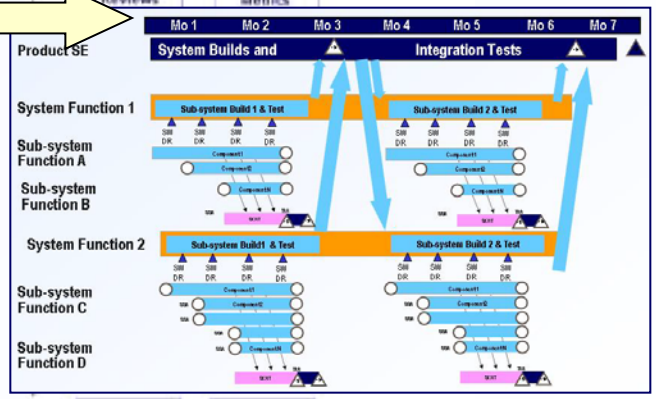
Functional Analysis and Allocation

Decompose functions & build schedule

Determine logical architecture alternatives; understand functional relationships; determine where and how functions are performed in the system

Synthesis

Define the system solution



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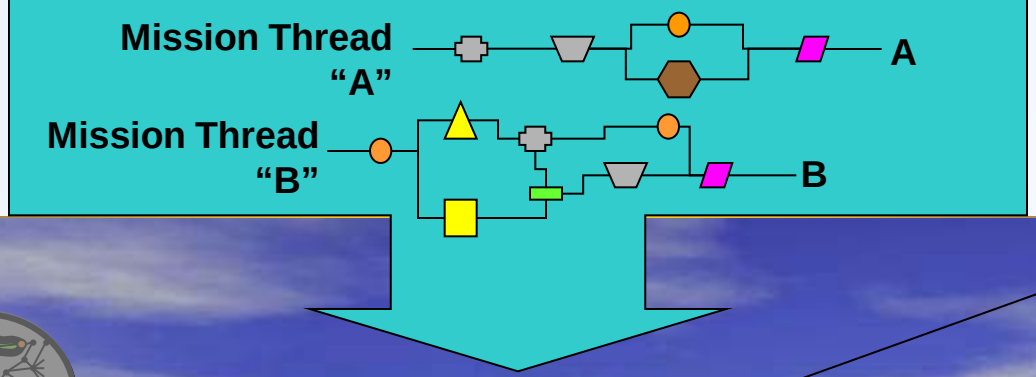
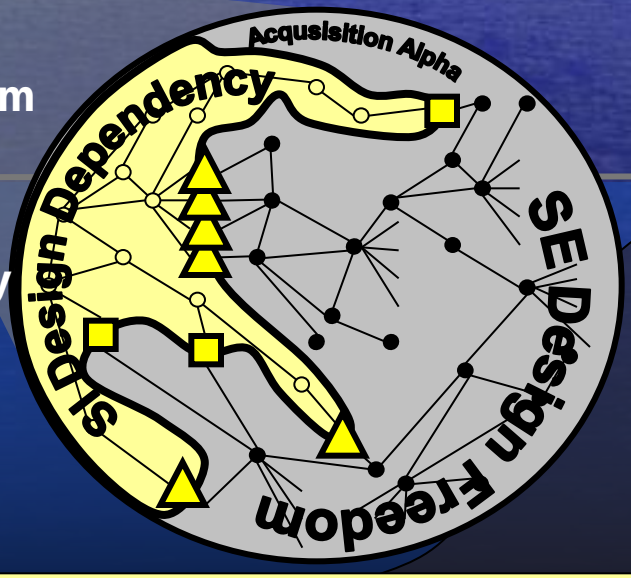


Mission Level Requirements Flow Into Programs of Record

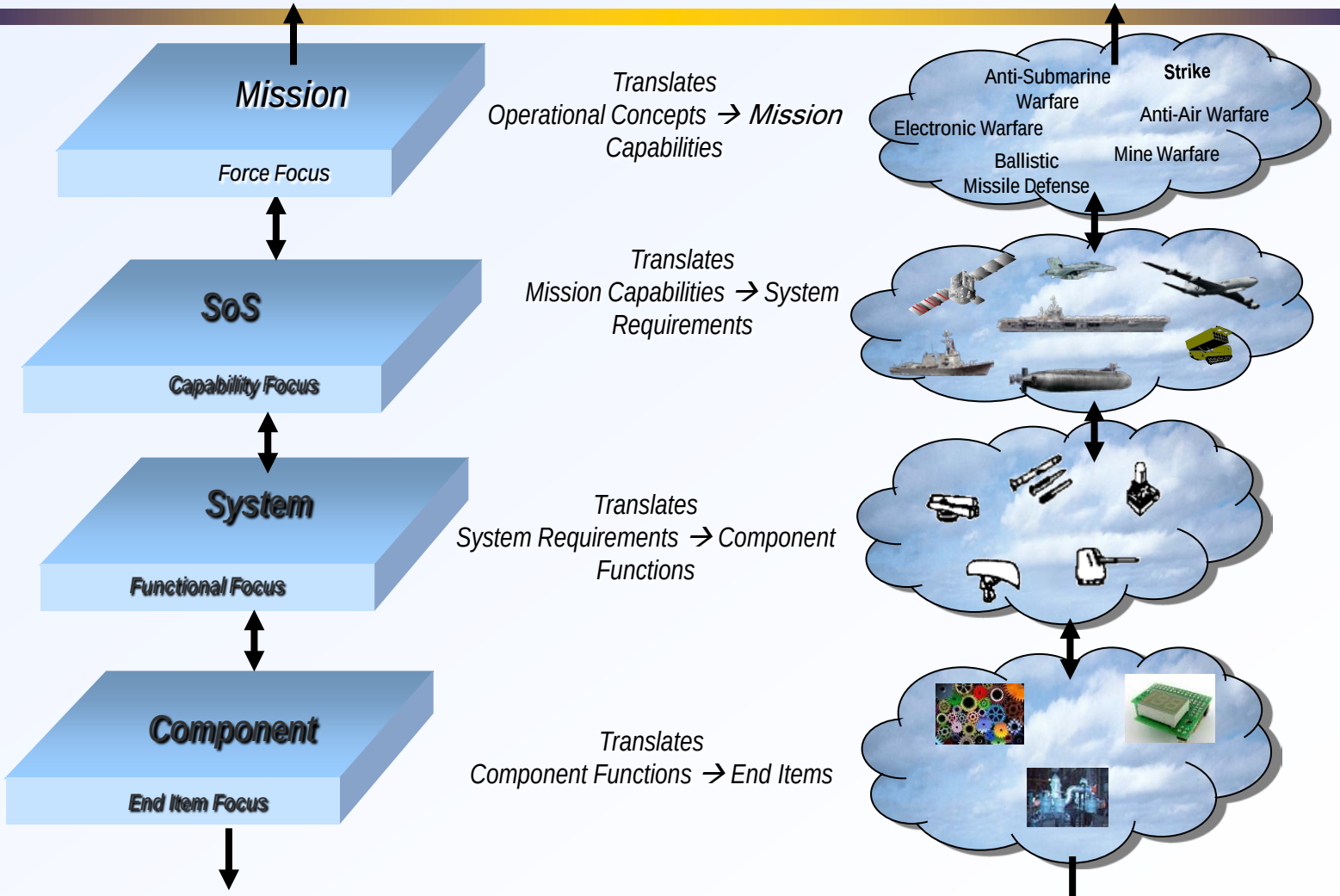
A Subset of System Requirements Addresses Integration for Mission Capability



Requirements Flow Down as Architectural Elements of Platforms and Systems

Multiple Missions, Multiple Acquisitions, Requirements Flowing to Different Levels Concurrently
A Highly Complex Engineering Endeavor Requiring Discipline, Competence and Tools

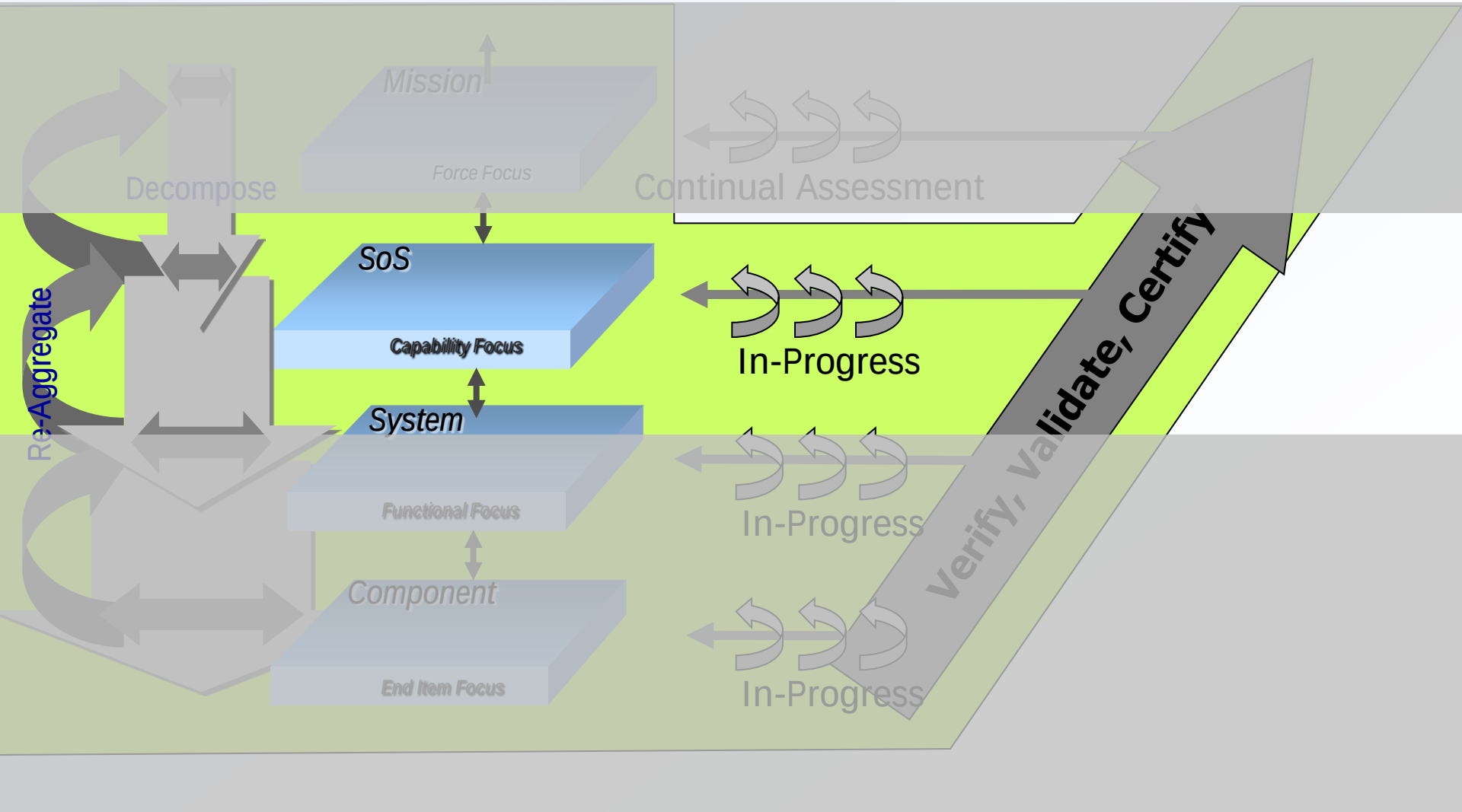
DoN Engineering of Systems
(a spectrum of Systems Engineering)



Systems Integration takes place at each level of the hierarchy and requirements are passed between levels of the hierarchy

System-of-Systems Integration

Requirements | Production | V, V&C



Chem-Bio Architecture Engineering: System of Systems Approach to Counter the Threat

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Sustained Combat Power

CB Threats & Hazards

Agent Delivery → Doses on Target → Downwind Dispersal → Doses Absorbed → Symptoms

Medical Pretreatment

Individual & Collective Protection

Medical Treatment

Information Systems

Contamination Avoidance and NBC Battle Management (Detection, Identification, Reconnaissance & Warning)

Installation Force Protection

Decontamination, Restoration

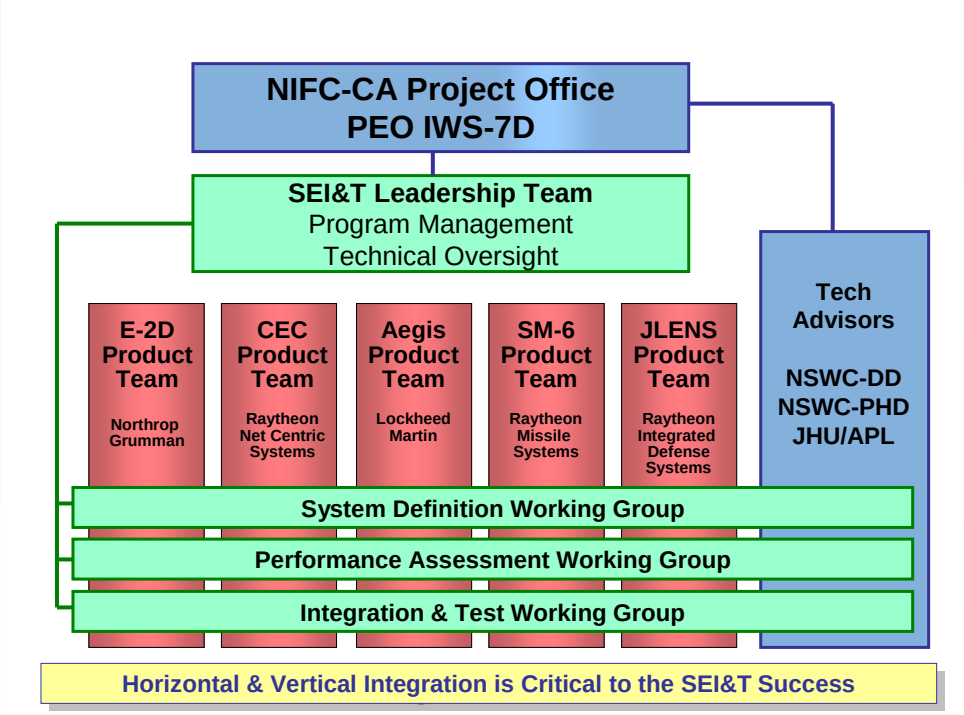
Chem-Bio Architecture Engineering Best Practices

- Architectures are useful in managing complexity
- Architecture framework (DODAF) facilitates the sharing of information and requirements among systems engineers and architects
- SE and Architecture tools are necessary to manage the complexity
- Managing CBRD requirements and gaps facilitates the identification of S&T opportunities that effect cross-Service capability
- Managing CBRD requirements for the services facilitates the identification of common elements resulting in life-cycle savings
- Open architecture concepts promote the ability to leverage needed subcomponent elements (specific algorithms from components rather than the total component)

Naval Integrated Fire Control – Counter Air (NIFC-CA)

Objective: Achieve Naval and Joint Integrated Fire Control capability against over-the-horizon and below-the-horizon AAW threats by distributing the AAW fire control loop across multiple PoR platforms.

Approach: Form a collaborative government/industry SoS systems engineering team by collecting lead engineers and managers from across all participating PoR systems. Develop IFC-unique operational concepts, systems engineering products and trade studies and allocate results to PoR programs.

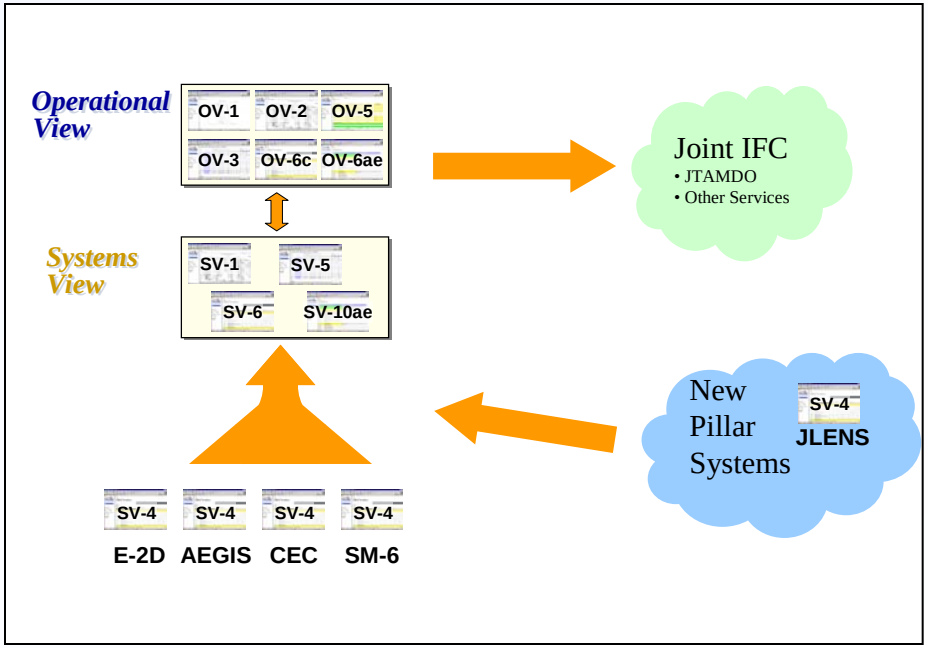


NIFC-CA Lessons Learned

Leadership, teaming and collaboration are essential to success for SoS development.

DODAF architecture is essential for definition and organization of SoS capability and the eventual allocation of unique functionality to existing and future PoR programs.

- Define capability within the OVs
- Compare OVs to similar SoS
- Expand the intermediate SVs
- Allocate functions to PoR SV-4s
- Add new PoRs via their SV-4s



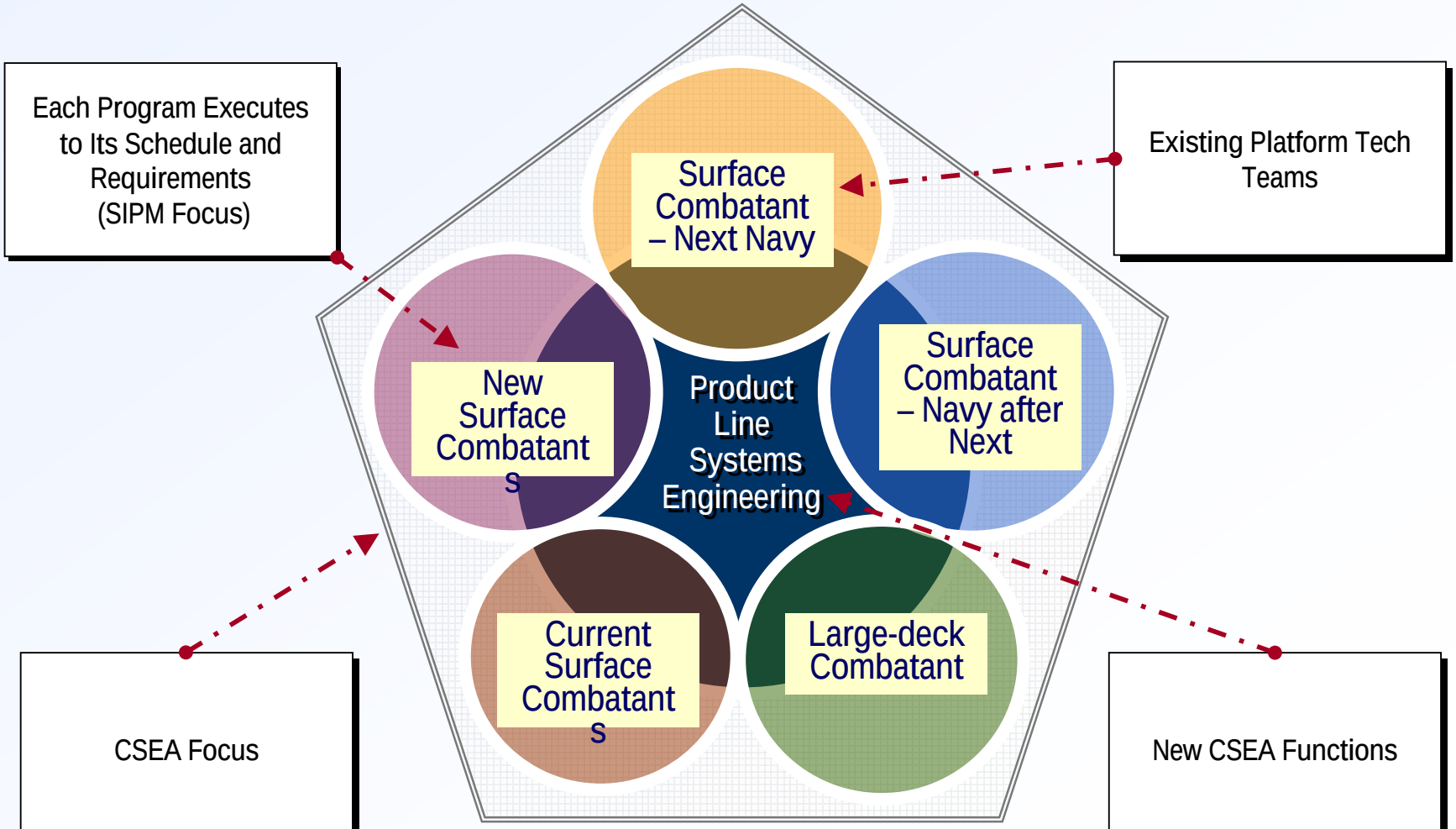
NIFC-CA Best Practice

Conduct SoS-unique systems analysis and trade studies as needed for critical functions.

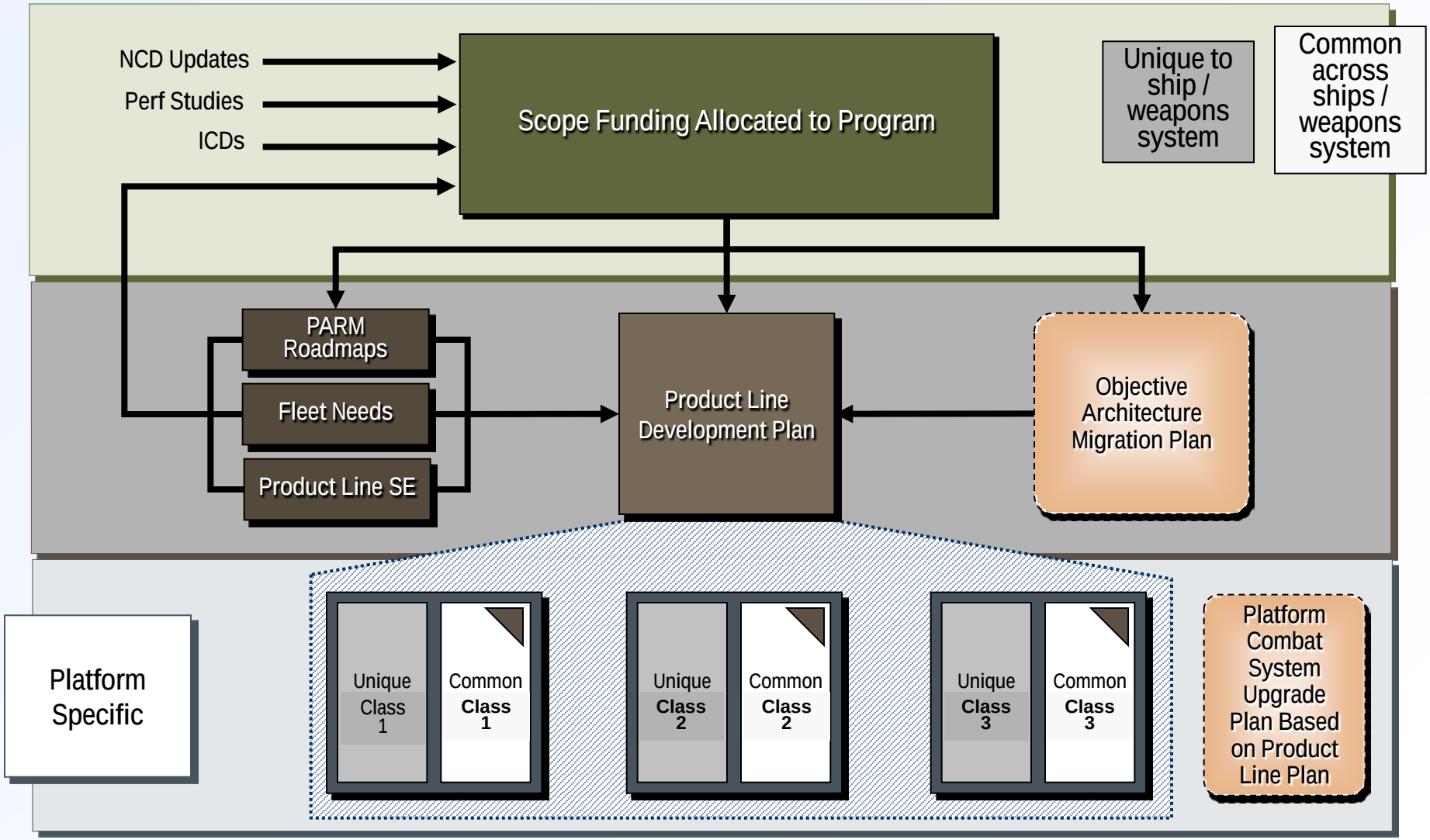
- Identify SoS MOEs (measures of effectiveness).
  - Unique goals and objectives to be achieved by the SoS in order to accomplish the SoS mission.
- Identify PoR MOPs (measures of performance).
  - Parameters and functions unique to each PoR that contribute to overall SoS MOEs.
- Analyze and trade functionality and performance across the SoS.
  - Quantify results against the MOPs and roll up to the overall MOEs
- Simulate and analyze SoS performance via low-fidelity (spreadsheets, MatLab tools) to higher-fidelity (federated PoR models) methods as feasible.

SoSE Combat Systems Engineering

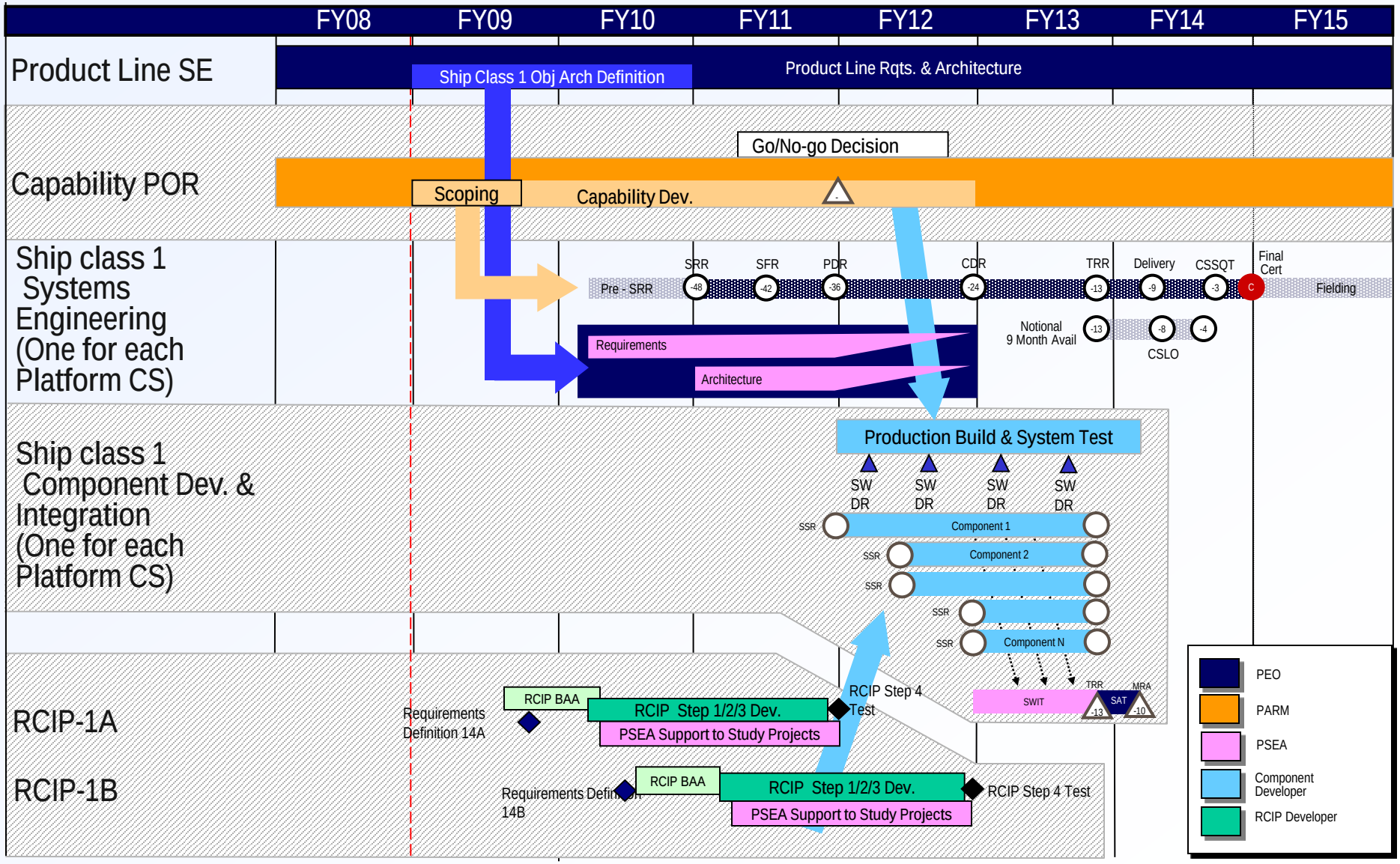
Combat Systems Engineering accomplished across platform combat systems via Product Line Approach



Desired Future State
Product Line Acquisition



Product Line SE / Upgrade Development Example – Notional Ship Class 1



Common Weapons Control System Background

- CWCS is:
  - Common system for preparing/launching various weapons across multiple warfare areas
  - Applicable to various platforms (surface and sub-surface)
  - Establishes open architecture environment for adapting/scaling new weapons/systems
  - Moves Navy (& potentially Joint) weapons control away from creating NEW & modifying closed stove-pipe systems
  - Leverages existing Naval systems (Tomahawk Weapons Control System, Navigation, C4I Systems, etc.)
- CWCS concept being evaluated by multiple NSWCDD department's systems engineers
- Systems engineering artifacts and system prototype under development

Establish Common Weapons Control System for Navy Platforms and Weapons

CWCS SoSE Approach

- Leverage current surface and submarine systems
  - Weapons Control
  - Navigation
  - C4I
  - Networks (ship and sub-based)
- Follow established systems engineering processes
- Leverage established systems engineering products
  - Architecture, weapon system requirements specs, interface requirements, employment concepts, scenarios, etc.
- Integrate existing functionality to provide benefit to warfighter and taxpayer
  - CWCS integrates two existing systems
    - Naval Fires Control System (NFCS)
    - Tactical Tomahawk Weapons Control System (TTWCS)
  - Integrates Marine & Army fires networks and capabilities to all surface combatants
  - Coordination of fires
  - Reduces overall program cost and lifecycle support

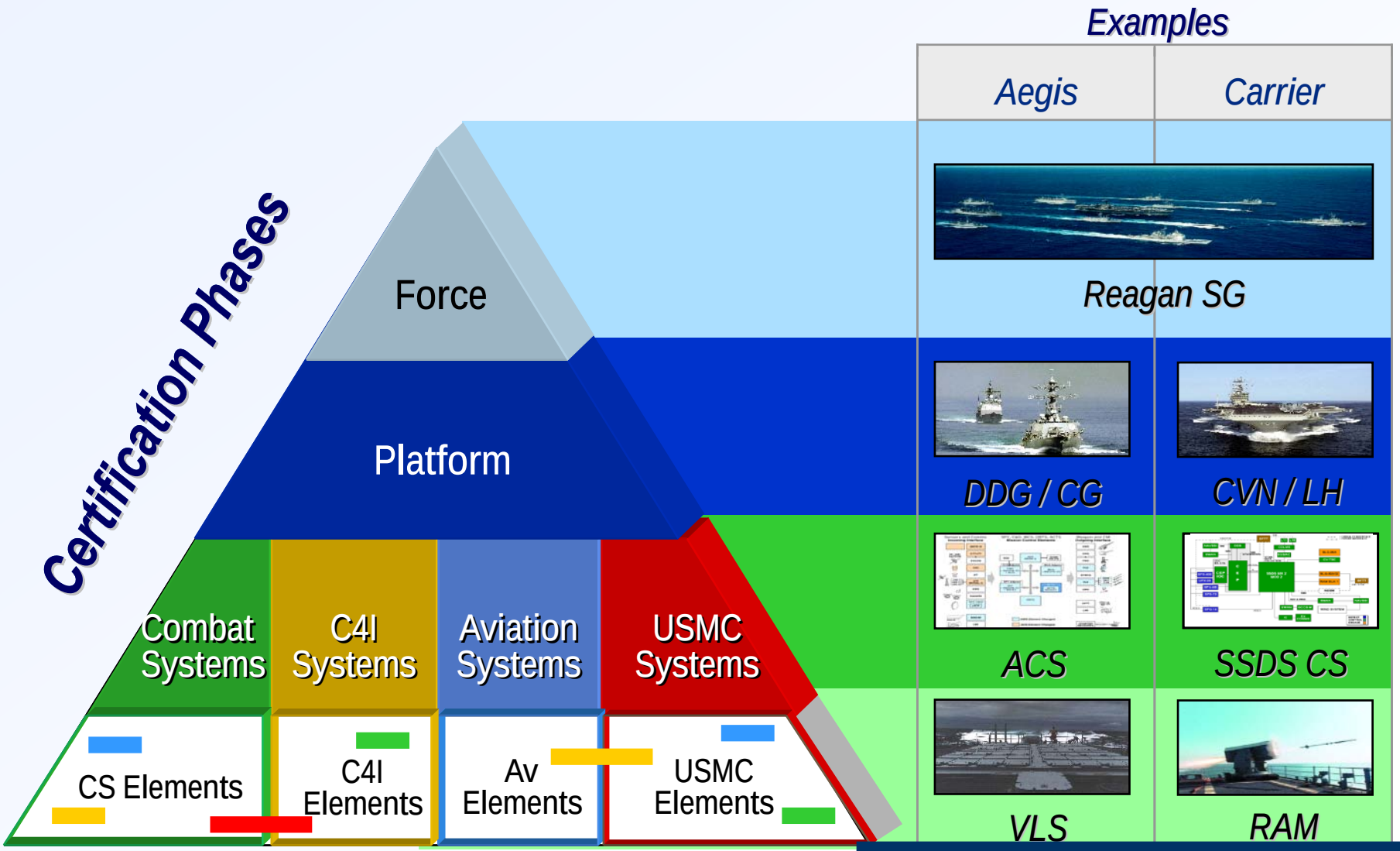
CWCS SoSE Approach

- Leverage training curricula and documentation
- Leverage established training pipelines
- Joint interoperable with various systems (end-to-end)
  - Tasking from multiple sources
  - Battle Management & Coordination Systems
  - Situational Awareness systems (e.g. GCCS-M, J,…)
  - Manages and deconflicts multiple weapon variants for simultaneous weapon prep/launch
  - Threat data, obstruction data, etc.
- Leverage existing tactical data analysis and extraction applications/tools
- Leverage combat systems training and simulation functionality

Combat Systems Certification
Situation Before 2004

- Combat System Certification Processes Varied Widely Across Systems and Programs
  - Certification did not Occur for all Combat System Elements
  - Combat System Certification for SSDS & ACDS Ships was not Conducted
    - Fielded Through Existing SEA62 Fleet Delivery Readiness Review (FDRR)
  - Platform Certification for Aegis Ships was not Conducted
    - Assumed as Part of Aegis Combat System Certification
  - Certification Criteria not well Defined or Understood
- In-Service Programs Viewed Certification Largely as a T&E Event Vice a Continuous Process Throughout System Definition And Development
  - Quality Issues Drove Test / Fix / Test Loop
    - Drove Perception That Certification is Long and Expensive
  - Various Test Efforts Were not well Coordinated
    - Developer, Cert, CSSQT, DT / OT

Combat Systems Certification
One Process – Four Phases



Pre-decisional Draft

Coordinating the Phases

- CS Cert is Focal Point for all Certification Activities
  - Coordinates and Aligns Element Certifications
  - Administers and / or Oversees Critical System Integration
  - Supports Platform Certification by Providing the Activities and Data to Fulfill the Warfare System-Related Platform Cert Criteria
    - Including Many of the WSIIT Requirements
  - Also Provides Process and Means to Address Corrective Actions Required as a Result of Platform / Interoperability Cert Assessments

Well Coordinated Phases – No Duplication

Achieving CS Cert Objectives

Certification is Both a Process and an Act of Attestment

- Continuous Assessment (Vice End-Game Only)
  - Objectively Assess the Progress of the Development Effort to Reduce the Risk that the System will be Ready to Certify on Schedule
    - Assessment of Progress Versus Plan
    - Verification of System Efficacy and Quality
    - Identification and Resolution of Potential Certification Issues
- Authorizations
  - Assess the Ability of a Specific Version of the System to Perform Specific, Well Defined Scenarios or to Perform a Limited Mission (Usually an At-Sea Test Or Trial)
  - Assess the Ability of the System to Operate Safely Within Documented Restrictions
- Certification Panels
  - Assess the Readiness of a Specific Version of the System to Perform the Broad Mission Requirements of the System (Readiness for Full, Unrestricted Fleet Use)
  - Assess the Ability of the System to Operate Safely

Process Value-Added

- Provides a Structured, Systematic Assessment Methodology
- Applies Full Rigor: Defines Certification Activities, Detailed Tasks, Work Products, and Applicable Metrics IAW Industry Standards
  - Establishes Expectations for Developer-Executed V&V / Certification Activities and Artifacts
  - Assesses Developer's V&V Work / Results
  - Defines Appropriate Degree of Independent Assessment Activity
- Fully Adapted to Evolutionary Acquisitions
- Coordinates With Other Critical Processes (e.g. Safety, CM, QA, etc.)
- Addresses: COTS / NDI, Reuse, HSI, Security, Safety, etc.
- Generates and Accumulates Technical Insight for Continuously Updated Assessments and Cert Status
- Builds in Accountability of the Cert Process Itself

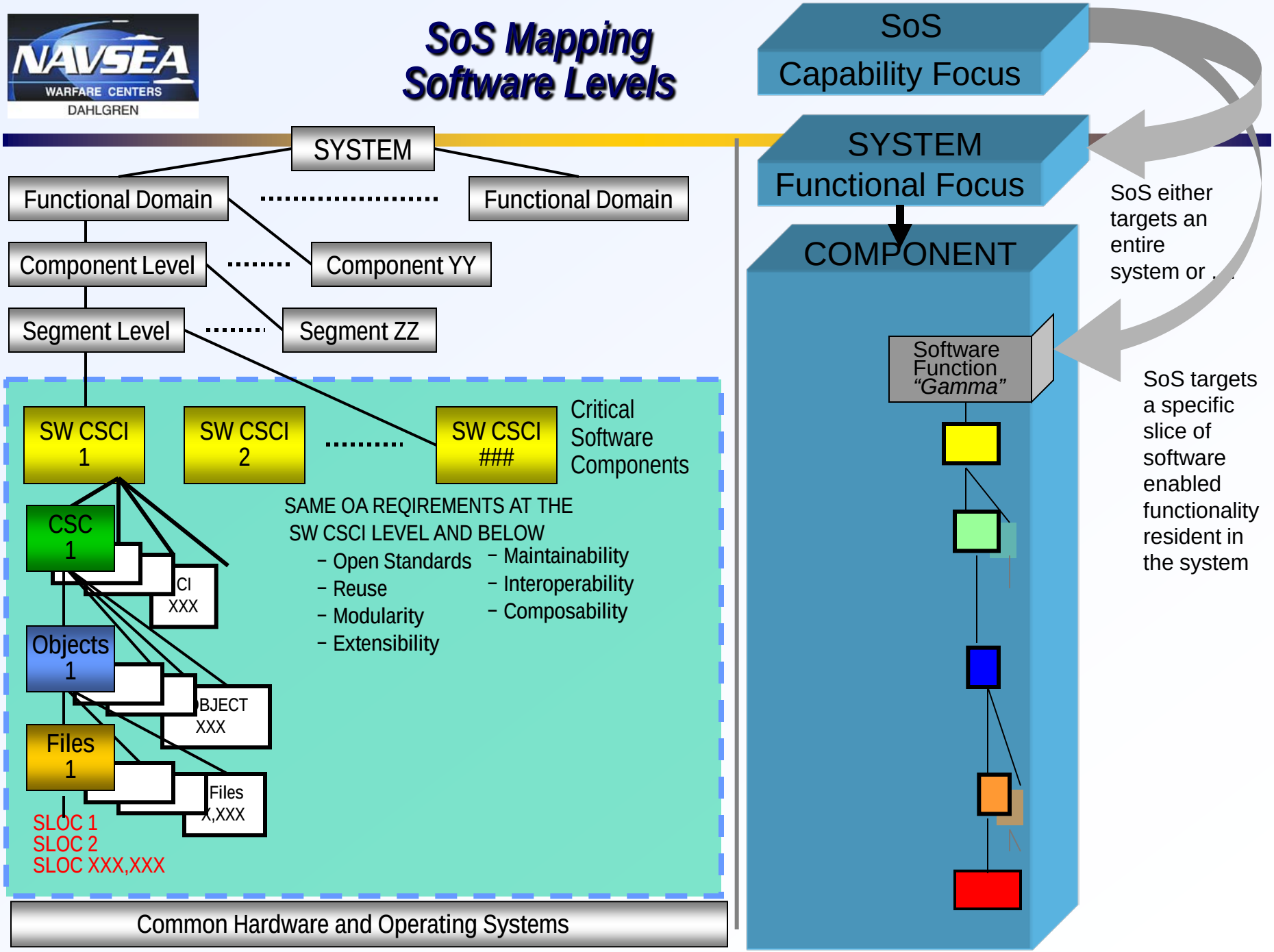
Detects and Eliminates Defects and Risks Earlier

Software Engineering and Development Applied Experience

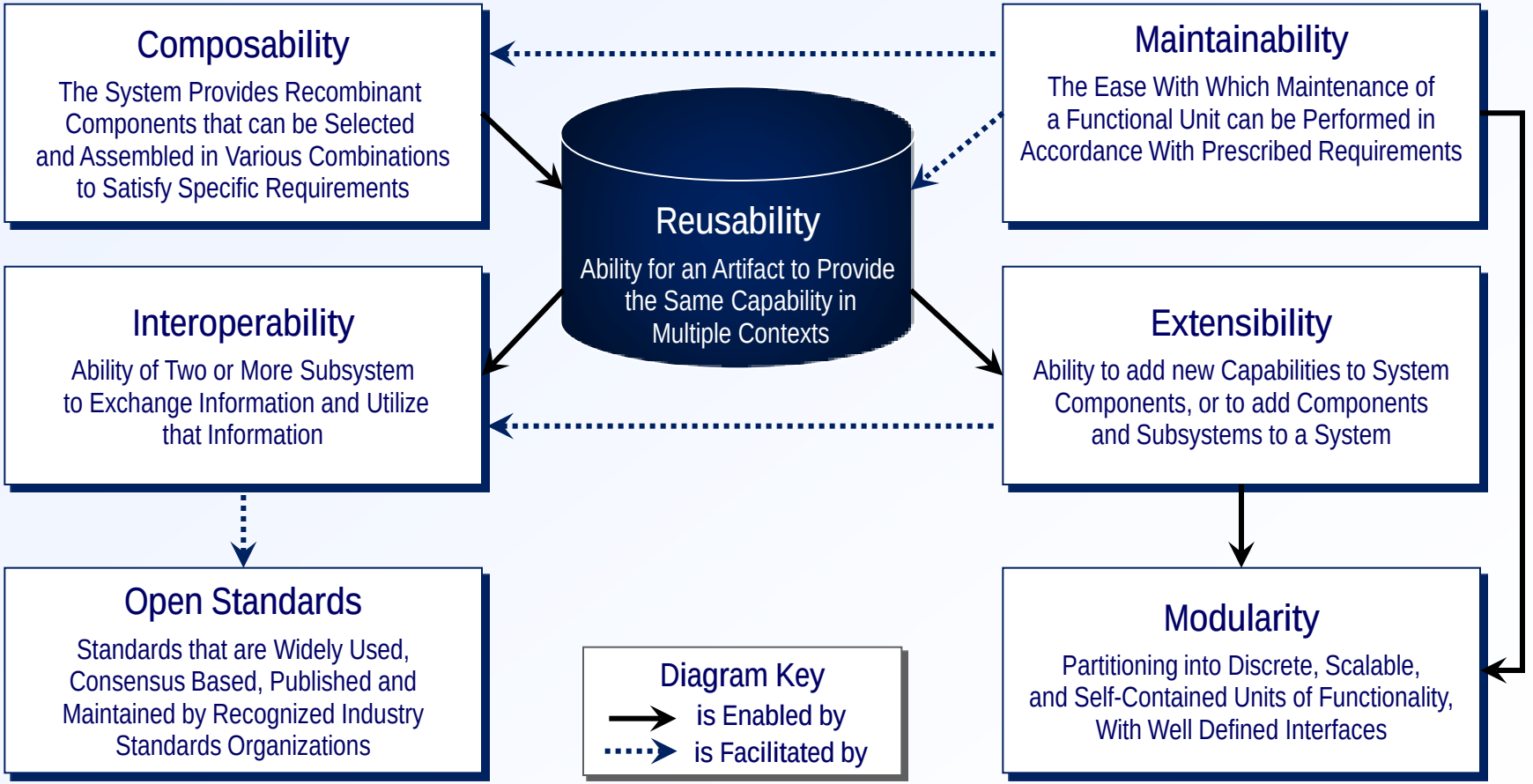
- NSWCDD has 50+ year history of providing full spectrum SW Engineering and actual SW Development for multiple Combat and Fire Control Systems
- Includes real-time, safety critical, complex algorithms, multi-process, multi-interface tactical and simulation sw design, code, and test
- Participation in cross organizational and cross discipline (SE/SW/Test) IPT and Leadership of Industry and Government Engineering SW Development IPTs
  - Pro-active SW expert participation in from Concept Development through System Requirements, System Development, Deployment, and Operational Support
- Demonstrated success in developing Open Architecture based multi-platform capable, re-usable, scalable, and maintainable software components

Applied Software Engineering and *Development* Expertise

SoS Mapping Software Levels



Software Lessons Learned
Open Architecture is more than just 'Reusability"

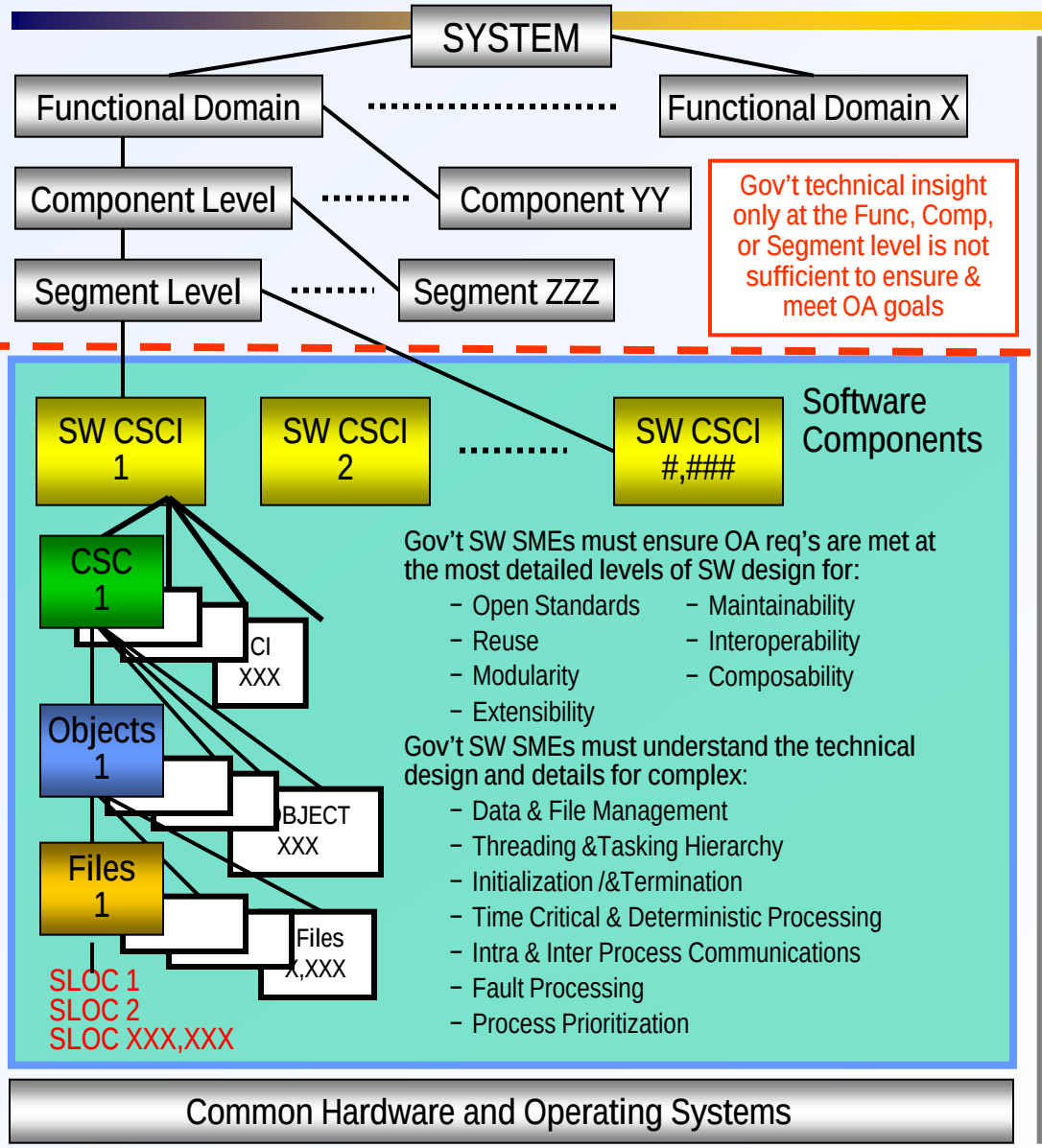


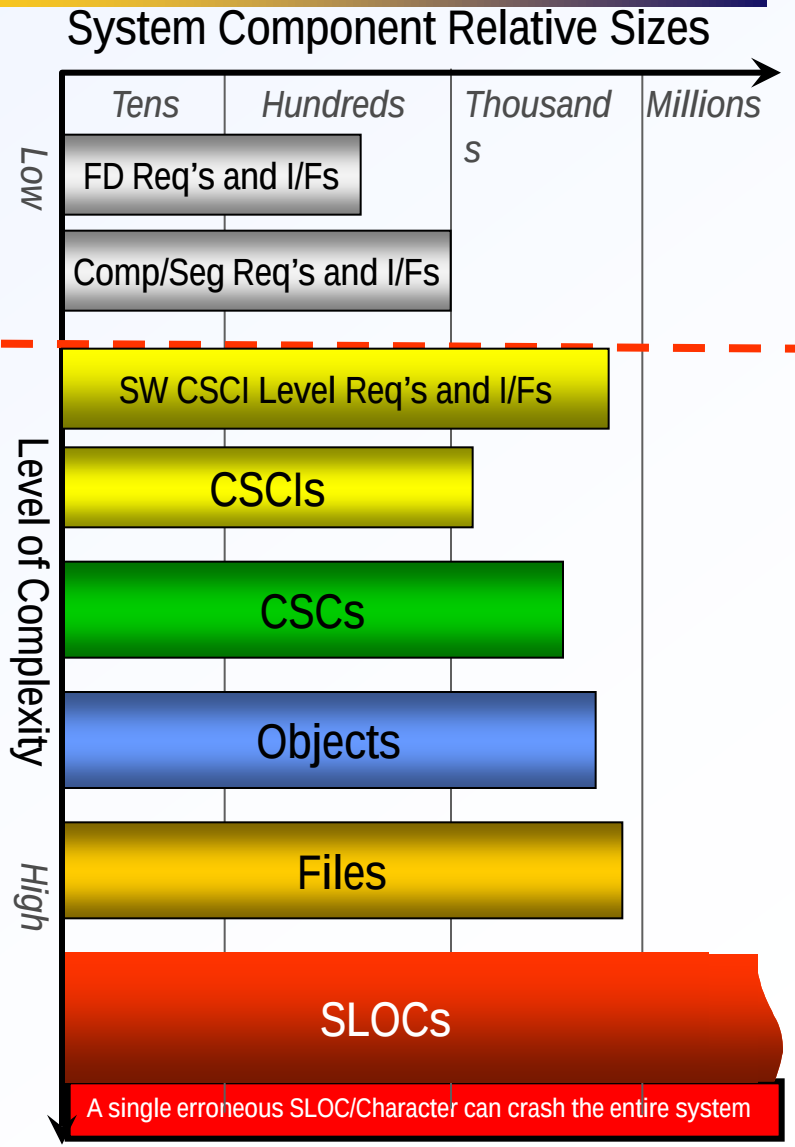
These OA "ILITIES" Cannot be Easily Verified by System Testing Alone.
Gov't SW Expertise Insight Into Design and Code is Required to Ensure Reusable Software.

Designing and Coding for These "ILITIES" is the Key to Saving Significant $$$$$$$$.

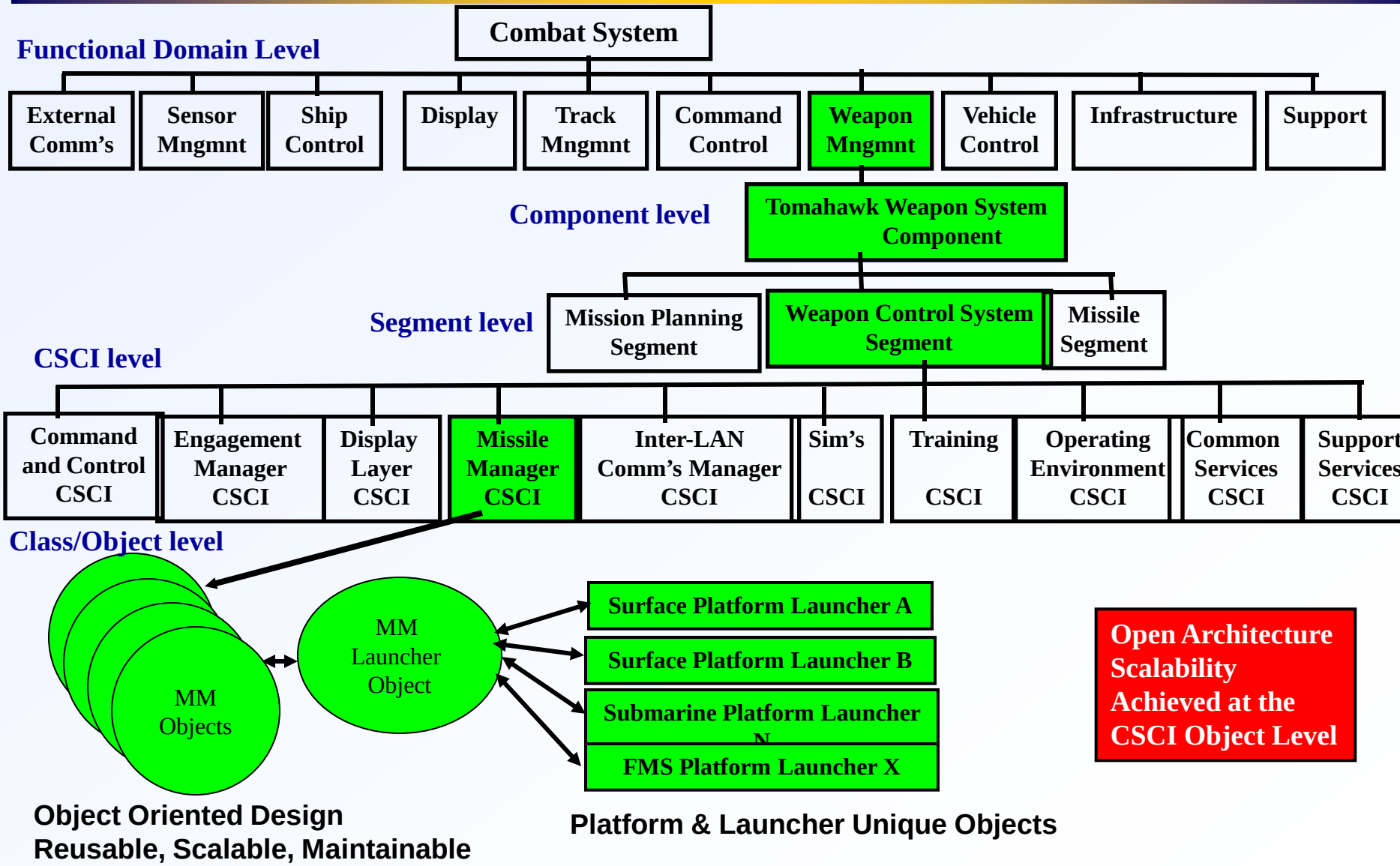
* Reference: OA Architectural Principles and Guidelines v 1.5.6, 2008, IBM, Eric M. Nelson, Acquisition Community Website (ACC) DAU Navy OA Website

SW Lessons Learned:
Levels of SW Complexity / Devil is in the Details





Open Architecture: Example Achieved at the CSCI and Class Level



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Wrap-Up
SoSE Key Points

- Tailoring the Systems Engineering Process
- Technical Considerations in System- and Family-of-Systems Engineering
- Distributing Functionality across Systems
- Leveraging Commonality
- Life-cycle Affordability
- Development for System Certification


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