Establishing an Operational Context for Early System-of-Systems Engineering Activities

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Bryan "Chum" Herdlick (CSEP-Acq.)

Global Engagement Department (GED)

Aviation Systems Analysis Group (GVS)

240.228.0556 **bryan.herdlick@jhuapl.edu**

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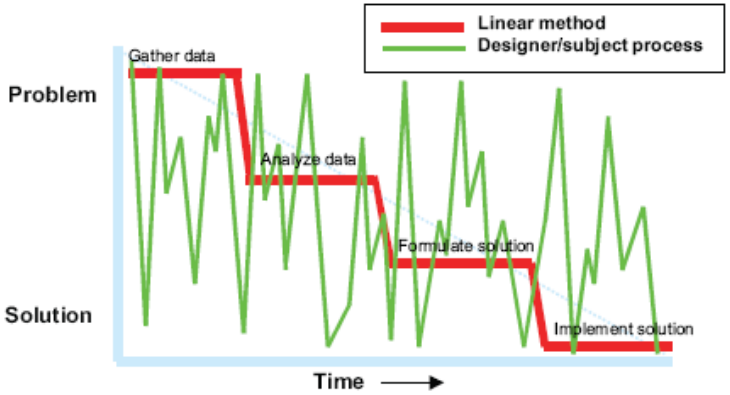
The Johns Hopkins University

APPLIED PHYSICS LABORATORY

System of Systems (SoS)

Context & Challenges

- Focus Area: International Council on Systems Engineering (INCOSE) Research Plan 2008-2020
- Exploration of SoS solution space is non-linear and messy
  - Requires ***simultaneous conduct*** of activities normally viewed as sequential by Department of Defense (DoD) acquisition and Systems Engineering (SE) processes
    - Concept Development
    - Operational Context Development
    - Requirements Development
    - Technical Development
    - Engineering Development



From: *Dialogue Mapping* [Conklin, 2005]

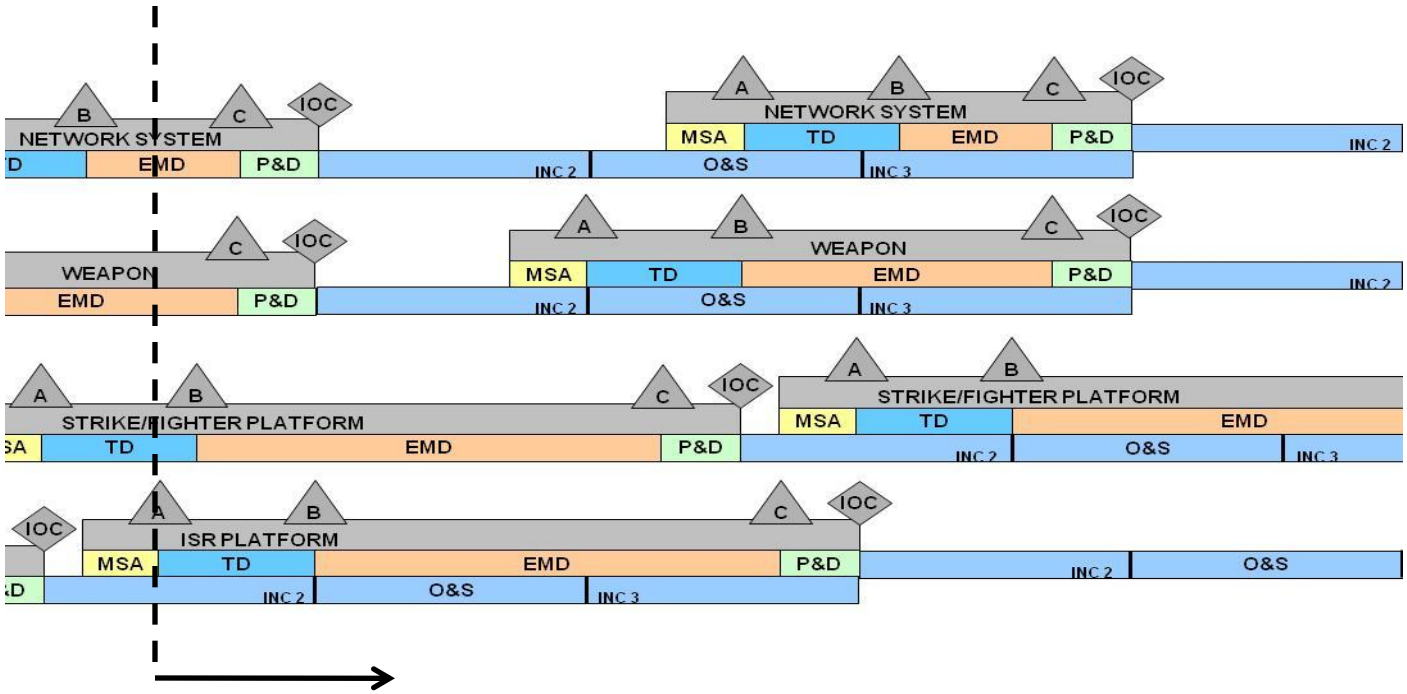
- Why?
  - Understanding the problem requires consideration of solutions!

Challenge: Distributed Development

Participating Programs Are Asynchronous

Constituent Systems

Major Defense Acquisition Programs (MDAPs)



SoS Process & Documents Must *Guide and Inform*

Simultaneous and Distributed

Concept Development, Technology Development, and Engineering & Manufacturing Development

SoS Development

Not Mainstream DoD Acquisition…but sanctioned

- Often intentionally conducted "outside" the DoD acquisition process
  - √ Technology Projects [DoDI 5000.2, Encl. 3, p.30]
    - √ Pre-MDAP development and demonstration
    - √ Focus on relevant, operational environments
  - X Exit of Tech Development Phase (only defined for MDAP context)
    - X Milestone B (MS B = transition to System Design & Development (SDD) and Engineering & Manufacturing Development (EMD))
    - √ Increment of militarily useful capability achieved
    - X Completion of a Capability Development Document (CDD)
    - X Completion of (***an acquisition) Concept of Operations (CONOPS)***
  - X EMD Phase (post MS B)
    - √ System Development
    - √ System Integration
    - √ Interoperability
  - X Milestone C (MS C) entry is an option
    - √ Implies everything up to MS C may be conducted outside an MDAP
    - √ ***Acquisition policy, process and documentation not mandated prior to MDAP***

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Defining an Operational Context

A best practice critical to system development

- SoS Concept of Operations (CONOPS)
  - An attempt to extend the application of recognized documentation to the realm of complex systems
  - Introduced in the DoD Guidebook for Systems Engineering (SE) of SoS [2008], but without significant detail regarding content
  - Further cemented in the SE lexicon by one of the Guidebook contributors in a recent article, but again, with limited details as to content or organization of the document
    - Systems Engineering Artifacts for SoS [Dahmann (et al.), 2011]

Defining an Operational Context

A best practice critical to system development

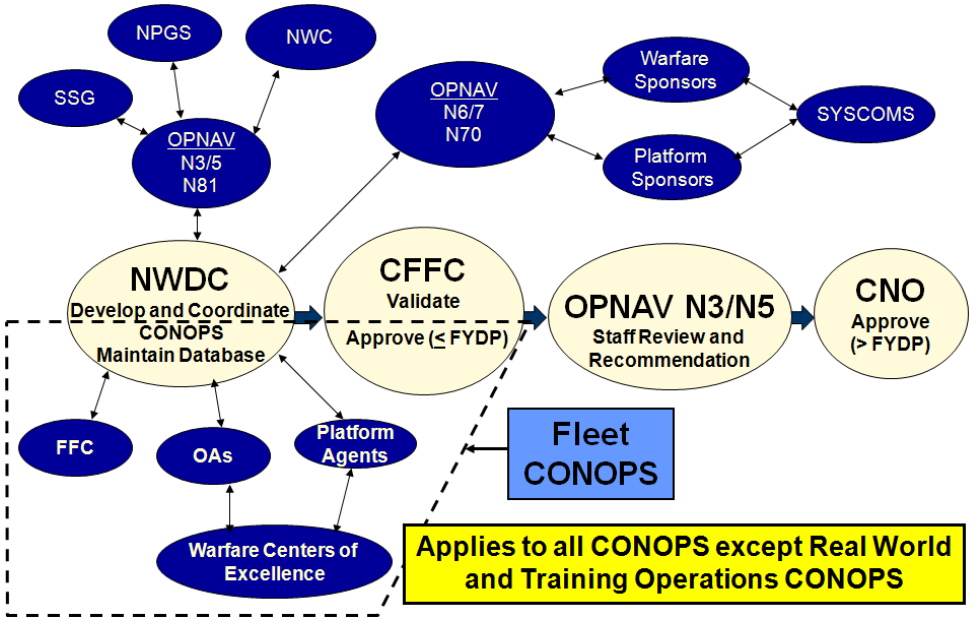
- CONOPS
  - Generally understood to be a document that captures the operational context necessary to guide the successful development and employment of a new system or capability
  - Exist in myriad variants
    - The term means different things to different people & organizations
    - Each variant of CONOPS is unique with respect to:
      - Purpose
      - Authorship / Ownership / Approval Agent(s)
      - Relationship to other documents
    - Content and organization guidance are intentionally not proscriptive, and tailoring is both authorized and encouraged
  - ***Are ill-suited for application to SoS-based capability development***

Fleet CONOPS vs. Acquisition CONOPS

The Fleet Forces Command (FFC) perspective

- Fleet CONOPS
  - Developed by FFC & Warfighters
  - Approved by Commander FFC (CFFC)
  - Specifically not “Real World” or “Training” CONOPS

- Acquisition CONOPS
  - Generated by Chief of Naval Operations Staff (OPNAV)
  - *NOT* approved by CFFC
  - Tracked in Naval Warfare Development Center (NWDC) database
    - *Questionable*



CFFC Fleet CONOPS Writer’s Guide

Fleet CONOPS

…which flavor would you prefer?

- Platform Wholeness
  - Within the Future Year Defense Plan (FYDP)
  - No scenarios
  - Platform description
  - Platform Operations (sufficiency & logistics)
  - Admin control & chain of command
  - DOTMLPF considerations

- Warfighting
  - Within the FYDP
  - Operational Scenarios
    - How a soon-to-field capability might be employed
      - ***Assumes development is already underway & performance understood***
  - DOTMLPF considerations

DOTMLPF: Doctrine, Organization, Training, Materiel, Leadership, Personnel & Facilities

Acquisition CONOPS

…which flavor would you prefer?

- A "preliminary" CONOPS
  - Integral to an Initial Capability Document (ICD) and the Material Development Decision (MDD)
  - Part of the initial requirements development process

- Mandated for Milestone B (MS B)
  - Affiliated with a Capability Development Document (CDD)
  - DoDI 5000.2, enclosures 4 and 5 → Clinger-Cohen Act
  - Within the FYDP

- A "Developmental System" CONOPS
  - DRAFT OPNAV Instruction 5401.xx of 2011 (in review)
  - Previously known as a Concept of Employment (***CONEMPS)***
  - ***Accompanies CDD at MS B***
  - ***Applies to pre-MDAP programs, MDAPs and Rapid Deployment Capability (RDC) programs***

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CONOPS

The wrong tool for the (SoS) job…

- CONOPS is not singular
  - Fleet
  - Acquisition
- Content and purpose are narrowly focused
  - Fleet: Operation of fielded (or soon to field) systems
  - Acquisition: The operational context for ***a*** new system or platform
    - Not developed (historically) for SoS-based Capabilities
- CONOPS are developed for other purposes as well…
  - Security
  - Maintenance
  - Training
  - Logistics
  - Operational

CONOPS Alternatives?

The DRMP → NO …but it has merit…

- The Design Reference Mission Profile
  - DRMP (often just DRM)
  - Content
    - Functional Profile
      - Actions performed by (or on) the system
      - Manufacturing, Storage, Operations, Maintenance, Disposal
      - Duration & frequency
    - Environmental Profile
      - Threat
      - Operating Conditions (temperature, shock, electromagnetic, etc.)
  - More narrow in scope than a CONOPS
  - Often greater detail than a CONOPS
  - Can be incorporated into a CONOPS
  - Is NOT a CONOPS
  - Name should be changed if a DRM(P) is ‘grown’ into a CONOPS

CONOPS Alternatives?

A Concept Proposal → NO …but it has merit…

- A Concept Proposal (White Paper)
  - OPNAV Instruction 5401.9
    - Navy Concept Generation and Concept Development (CGCD) Program
  - Supports pursuit of potential solutions through:
    - Analytical studies
    - Workshops
    - Experimentation
  - Envisions transition of solutions to responsible agencies for action and implementation
    - Initiates or informs technology and engineering development
  - Unique and beneficial content
    - Problem / Gap / Opportunity
    - Capability / Candidate Solution(s)
    - Risks & Mitigation
    - Plan of Action and Milestones (POA&M)
  - The Navy's CGCD process does NOT develop CONOPS

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CONOPS Alternatives?

An OCD → Perhaps…for purpose & framework…

- Operational Concept Description
  - Industry Standard: ANSI / AIAA G-043-1992
    - American National Standards Institute
    - American Institute for Aeronautics & Astronautics
  - Both a technique *and* a document
  - Serves to:
    - Describe system characteristics from an operational perspective
    - Facilitate understanding of system goals among participants
      - Users, buyers, implementers, architects, testers and managers
    - Form a basis for long-range operations planning
    - Provide guidance for development of system definition documents
      - System specification and interface specification
    - Describe the user organization and mission from an integrated user / system point of view
    - Support evaluation of system design
  - Should be developed during concept definition

The Operational Concept Document

A composite solution

- Title derives from:
  - Handbook of Systems Engineering and Management
  - ANSI / AIAA G-043-1992
- Content compiled from:
  - ANSI / AIAA G-043-1992
  - Concept Proposal (White Paper)
  - DRMP
  - Acquisition CONOPS
  - Fleet CONOPS
- Organization based on:
  - ANSI / AIAA G-043-1992
  - Common themes and sections across other documents

Operational Concept Document
Content & Organization (1 of 9)

- Signature Page
  - Concurrence & Endorsement (only)
    - Not formally approved → this is a collaborative process & document
- Record of Changes
  - Identifies conditions and schedule for review & update
  - Identifies prime integrator for SoS / capability as responsible
- Executive Summary
  - ***Derived from:*** Fleet CONOPS
  - Warfighting Gap & Capability Proposed
  - SoS (constituent systems / engineering trade space)
  - Assumptions / Limitations / Constraints
  - Timeline (POA&M)
  - DOTMLPF Impacts

Operational Concept Document

Content & Organization (2 of 9)

- Document Overview
  - Purpose
    - Facilitates communication & collaboration
    - Obtains consensus among acquirer, developer, support and user agencies on the operational concept for a SoS-based capability
    - Communicates the composite capability between users & developers (bi-directional information flow)
    - Captures results of system-level and SoS-level performance analysis to aid in characterizing capabilities and limitations
    - Facilitates understanding of the SoS-based capability between users, buyers, implementers, architects, testers and managers
    - Forms a basis for long-range planning and the development of system definition documents
      - System specifications, interface specifications, etc.
  - Title
    - Derives from the Handbook of SE and Mgt, and Industry Guidance
  - Relationship to other documents
    - See backup slides (if desired)

Operational Concept Document

Content & Organization (3 of 9)

- Mission and Objectives
  - Derived from: ***CONOPS (multiple variants)***
  - Mission
  - Success Criteria
  - Target Set(s)
  - Threat(s)
  - Current Systems & Capabilities (what we CAN do today)

- Warfighting Gap
  - Derived from: ***Concept Proposal***
  - Current or future military PROBLEM for which there is no adequate solution given currently fielded or funded capabilities
  - Opportunity for significant advancement in warfighting capability that can be achieved through the modification and integrated application of existing systems

Operational Concept Document
Content & Organization (4 of 9)

- Scope of Development Effort
  - Derived from: ***Concept Proposal***
  - Identify Assumptions, Limitations & Constraints
    - Constrain / contain the problem
    - Manage expectations relative to capabilities / solution space
  - Identify general timeframe for development and fielding

- Concept / Capability Description
  - Derived from: ***Concept Proposal***
  - Identify
    - Warfighting capability
    - SoS constituent platforms / systems
      - Characterize functions within the context of the SoS / capability
      - ***Introduce functional block diagrams (precursors to architecture views)***

Operational Concept Document

Content & Organization (5 of 9)

- Design Trade Space
  - Derived from: ***N/A (added for SoS-based capability)***
  - Interoperability Aspects
  - Sensor Performance
  - Platform Performance
  - Weapon Performance
  - ***Deviations from current system function and performance should be highlighted as "delta requirements"***
    - ***Includes any fielded performance beyond that funded and required by existing specifications and/or "threshold" requirements***

Operational Concept Document
Content & Organization (6 of 9)

- Operational Scenario(s)
  - Derived from: ***Composite / Multiple***
  - Mission / Objective
  - Success Criteria
  - Employment Modes / Methods
  - Implied performance of constituent systems
    - ***Explicit and/or derived design requirements***
  - Information Exchange & Decisionmaking
  - Mission planning tools, training, controls & displays
    - ***Explicit and/or derived HMI requirements***
  - How the new system / capability adds value (warfighting utility)
  - What the system should NOT do
    - ***Boundary conditions, degraded operations, etc.***

Operational Concept Document
Content & Organization (7 of 9)

- Functional Profile
  - Derived from: ***DRMP***
  - Should align with previously presented operational scenario(s)
  - ***Detailed time scale of all unique functions that must be performed by (or on) the constituent systems*** pursuant to the SoS-based capability
  - Deviations from current system operation & support profiles should be highlighted as ***"delta requirements"*** for the constituent systems
  - Format: Table (options: flow chart, outline)
- Environmental Profile
  - Derived from: ***DRMP***
  - Should align with previously presented operational scenario(s)
  - ***Detailed time scale of all unique environments to which the constituent systems will be exposed*** pursuant to delivering the SoS-based capability
  - Deviations from current system operation & support profiles should be highlighted as ***"delta requirements"*** for the constituent systems
  - Format: Table (options: flow chart, outline)

Operational Concept Document
Content & Organization (8 of 9)

- Capability Characterization Strategy
  - Requirements for research and analysis necessary to characterize the performance of the SoS in the context of the desired capability
    - Modeling & Simulation
    - System Level Testing
    - System Integration & Verification
    - Operational Experimentation
    - Live Demonstrations
    - Related / additional studies
  - Unique to the development of an SoS-based capability
  - Similar to content recommended for a “Test and Evaluation Strategy” (TES) for a MDAP

- Action Plan (POA&M)
  - An integrated master schedule that spans constituent systems, development & integration efforts, and characterization activities

Operational Concept Document
Content & Organization (9 of 9)

- Issues & Risks
  - Derived From: Concept Proposal
  - Challenges in SoS development may include:
    - Integration
    - Technological
    - Organizational
    - Stakeholder & User Acceptance
    - Security Environment(s)
- Considerations (DOTMLPF)
- Appendices
  - Performance Characterization (analysis results)
  - SoS Design Trade Decisions
  - Mission Planning (Tools, Controls & Displays)

OCD Development References

- **INCOSE Research Plan: 2008-2020 [Ferris, 2008]**
- **System of Systems Lead Systems Integrators: Where Do They Spend Their Time and What Makes Them More or Less Efficient? [Lane & Boehm, 2008]**
- **Systems Engineering Guide for Systems of Systems [ODUSD(A&T)SSE, 2008]**
- **"Wicked Problems and Social Complexity"; Chapter 1 of *Dialogue Mapping: building Shared Understanding of Wicked Problems* [Conklin, 2005]**
- **Handbook of Systems Engineering and Management [Sage & Rouse, 1999]**
- **INCOSE Handbook (version 3.1)**
- **Operation of the Defense Acquisition System, Department of Defense Instruction 5000.2 [2008]**
- **Joint Capabilities Integration and Development System, Chairman Joint Chiefs of Staff Instruction 3170.01 (series)**
- **IEEE Standard 1362 [1998; rev 2007]**
- **Fleet CONOPS Writer's Guide [FFC Manual, 2009]**
- **Developmental System Concept of Operations [Draft OPNAVINST 5401.xx, 2011]**
- **USAF CONOPS Development Instruction [AFI 10-2801, 2005]**
- **"Laying the Foundation for Successful Systems Engineering [Skolnick & Wilkins, 2000]**
- **"Pre-Milestone A and Early Phase systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition" [NRC, USAF Studies Board, 2008]**
- **Ministry of Defense Architecture Framework (MODAF) M-10-13**
- **Design Reference Mission Profile Development Guidelines [ASN(RD&A), TB # ABM 1002-03, 2002]**
- **CONOPS Template [DHS Acquisition Instruction / Guidebook #102-01-001: Appendix F, 2008]**
- **Operational Concept Description (Data Item Description) DI-IPSC-81430A**
- **Guide for the Preparation of Operational Concept Documents [ANSI / AIAA G-043-1992]**

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BACKUP SLIDES

CONTEXT ONLY
(NOT PART OF THE ARTICLE)

Relationship to Other Documents

The SoS Development Context

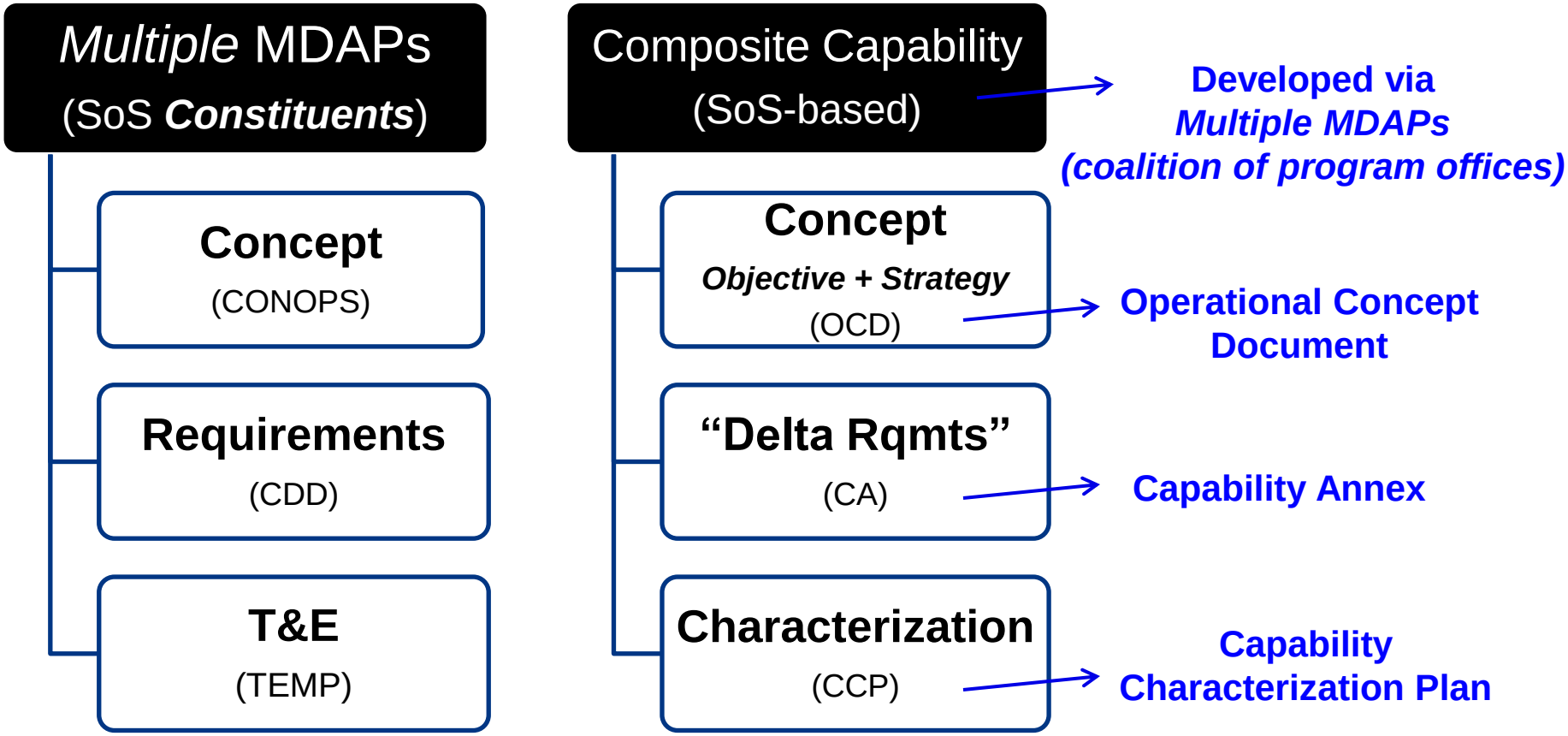
- ***Question:*** How does the OCD facilitate the SoS development process?

- ***Answer:*** By establishing an operational context that informs and guides…
  - Exploration of the engineering trade space
  - Characterization of performance at the SoS / capability level
    - Exceeds the scope of individual MDAP testing programs

- ***Answer:*** Through identification of "delta requirements" that influence the constituent systems (participating MDAPs)
  - Informs the development and/or modification of platforms, systems and weapons in the associated kill-chain(s) to achieve a composite (i.e. SoS-based) capability

SoS-based Capability Development

Systems Engineering Rigor…reflected in documentation



Compatible with *and* <u>*augments*</u> DoD acquisition processes, as it is *dependent* upon MDAPs for execution!

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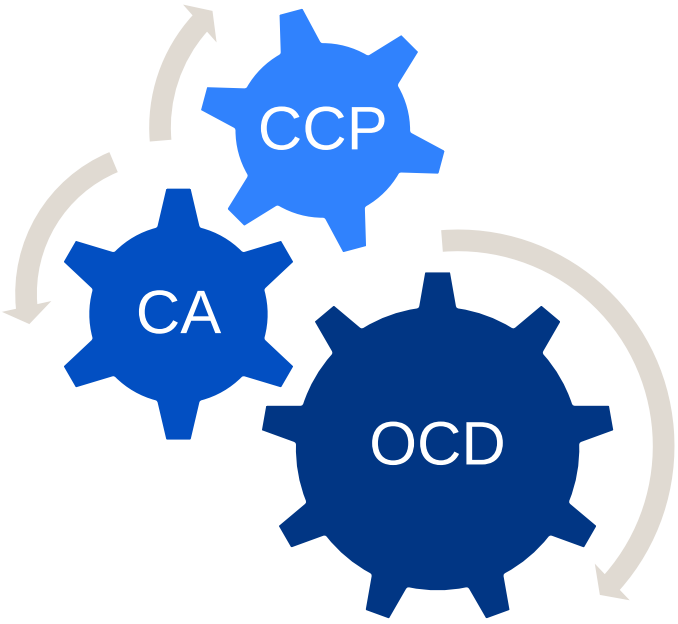
SoS-based Capability Development

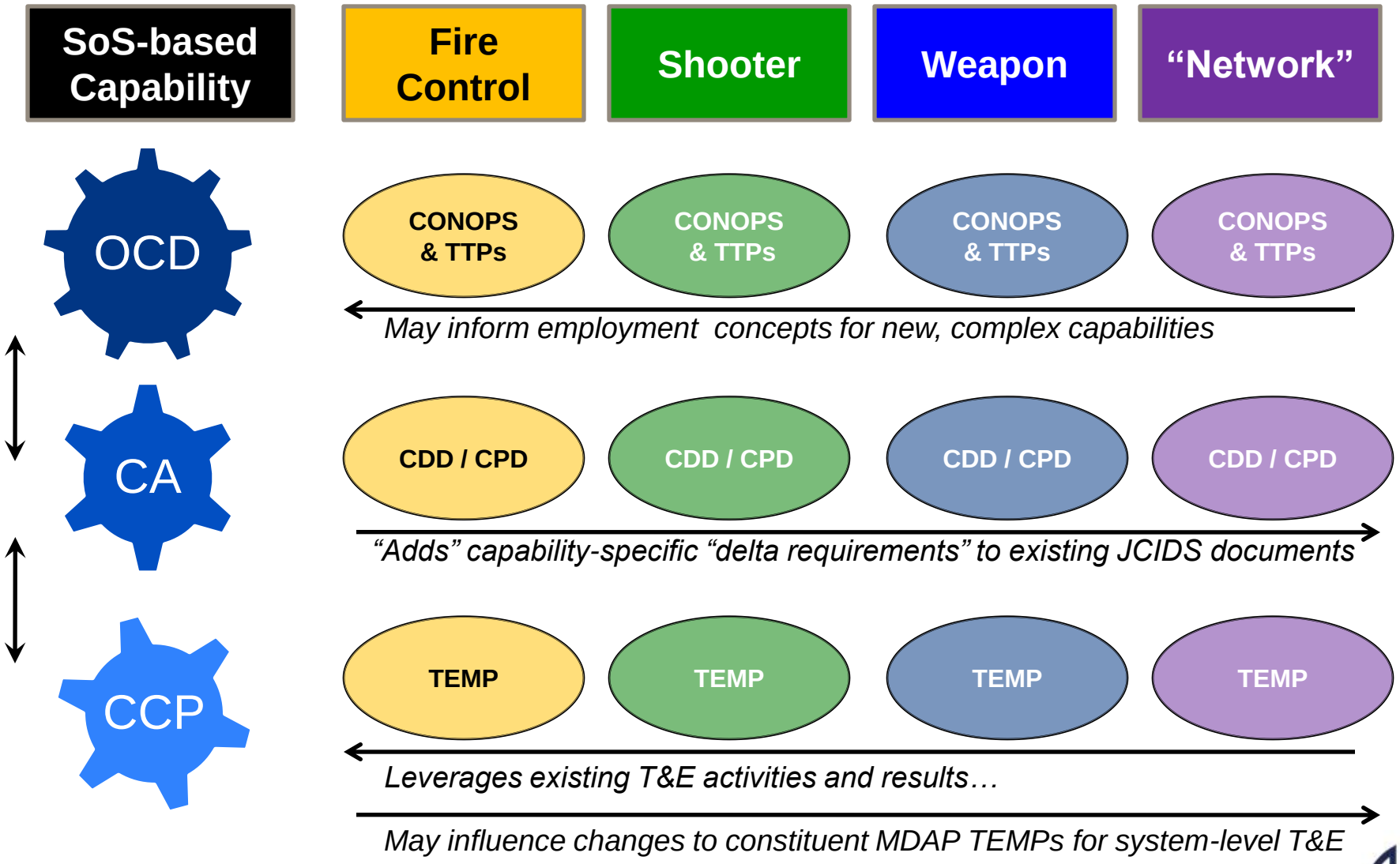
Documentation



- Operational Concept Document
  - Superior alternative to CONOPS
  - Context & process for identifying capability-specific “delta requirements”
  - Shapes the collaborative development environment (cross-MDAP scope)
- Capability Annex
  - Augments constituent program CDDs
- Capability Characterization Plan

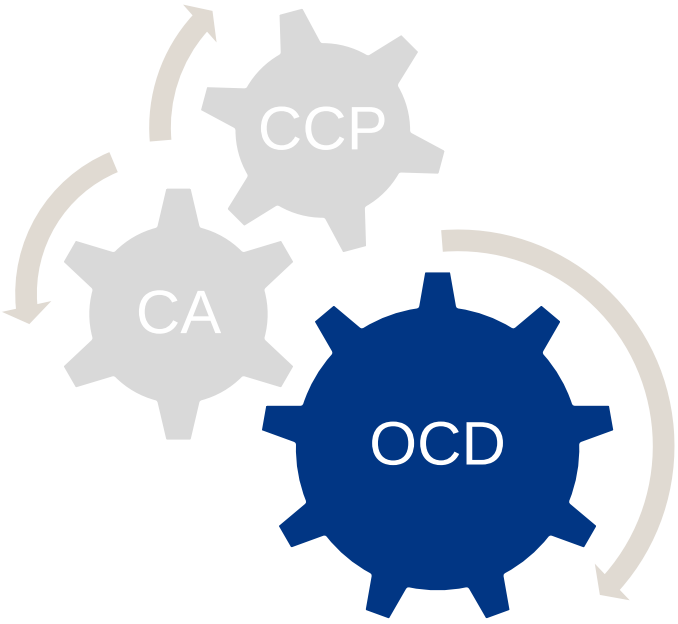
Documents are ***interdependent*** & must remain aligned

Documentation relationships



Shaping the collaborative environment

Step #1: Agreeing on the concept

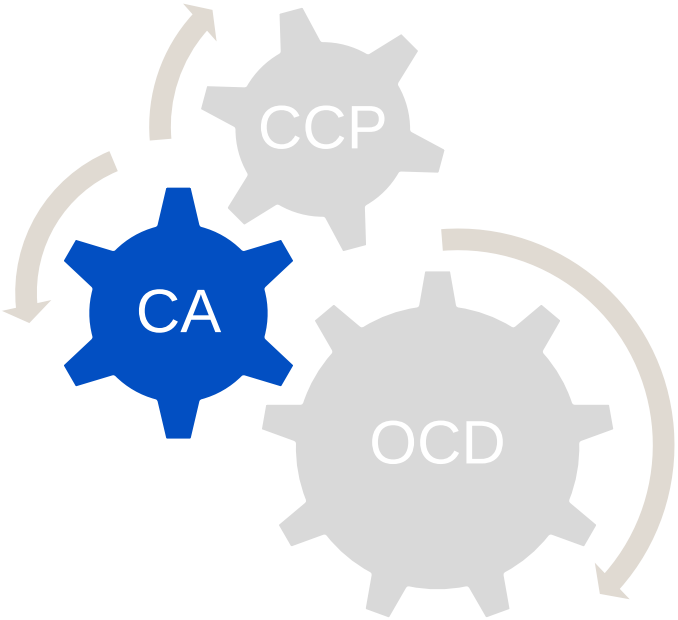


- Operational Concept Document
  - Derives from:
    - Handbook of Systems Engineering and Management (definition)
    - ANSI / AIAA G-043-1992
  - Modified to leverage guidance for:
    - Concept Proposals
    - Operational Concept Descriptions
    - Acquisition CONOPS
    - Fleet CONOPS
    - Design Reference Mission Profiles

Scope transcends constituent systems and MDAP offices

Implementing the SoS via MDAPs

Capability-specific "Delta Requirements"

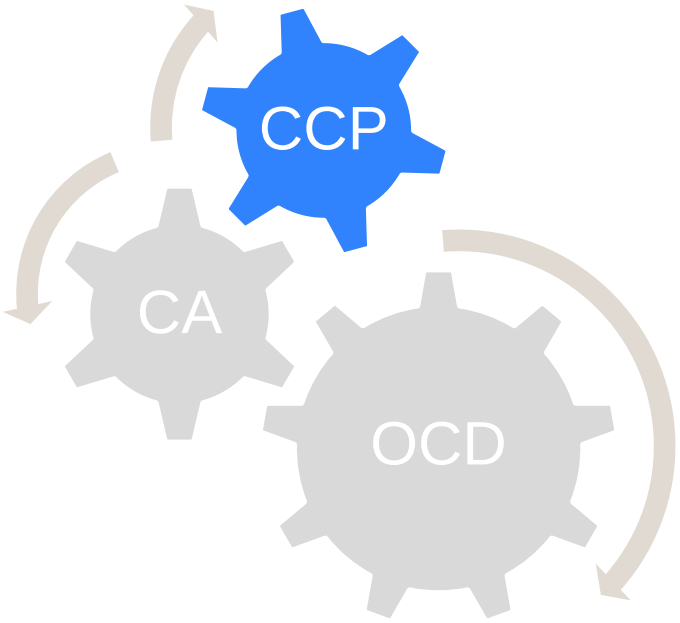


- Capability Annex
  - Captures capability-specific "delta requirements" for constituent systems
    - Informed by the OCD
  - Functional Decomposition
    - Echo of that presented in the OCD
    - May progress to physical allocation
  - High-level / SoS-focused Architecture
    - Interoperability Viewpoint (?)

CA intended to augment the CDD for each constituent system

Capability Characterization

Recommended role for T&E in application to SoS



- Capability Characterization Plan
  - Studies and preliminary analyses
  - Live
    - Demo
    - Flight Testing
    - Fleet Battle Experiments
  - Virtual
    - M&S (Operator in the Loop)
  - Constructive
    - M&S (Monte Carlo)

Capability is assessed continuously and progressively, with information from all activities supporting Observations of Operational Capability and informing fielding decisions

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Assessing Capability Maturity

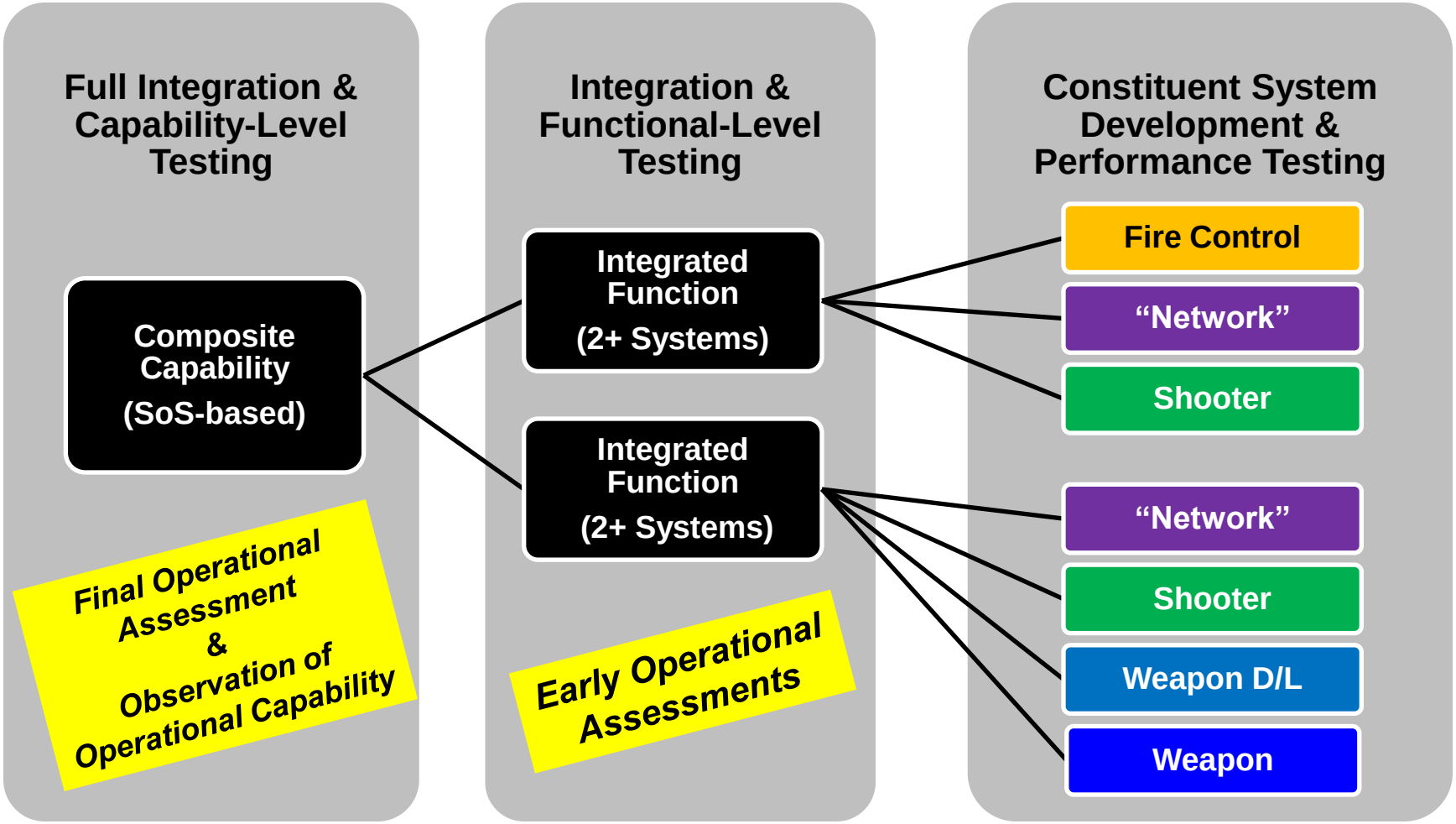
An incremental, multi-faceted approach

- "As-Is" Baseline Performance
  - Existing performance (actual, observed, as-tested / fielded)
    - Independent SoS constituents
    - Combined systems / functions

- "To-Be" Desired Performance
  - System-level Performance
    - Independent SoS-constituents
    - Focus: Critical Technical Parameters (CTPs)
  - Integrated Systems Performance
    - Investigates 'building blocks' to full capability
    - Focus: Integrated Function Performance Measures (IFPMs)
  - Capability Maturity
    - Achievement of an "increment of warfighting utility"
    - Focus: Growth in the context of a desired capability
      - As defined by "objective" statements / values

Characterizing SoS-based Capabilities

Test Activities & Responsibility



Capability Characterization Plan

Derived from Defense Acquisition Guidebook (TEMP)

- Integrated Master Schedule
  - Independent Testing
    - Critical single program activities
  - Cooperative Testing
    - Multiple programs
- Decomposition & Hierarchy
  - ***As reflected in the CA***
    - Composite Capability
    - Integrated Functions
      - "Derived Requirements"
    - System-level Performance
      - "Derived Requirements"
- Resource Requirements
  - Specific to cooperative testing
- Scenario(s)
  - ***As derived from OCD***
- Considerations
  - Modeling, simulation & analysis
  - Test conditions
  - Sample size
  - Interoperability
  - Information Assurance
  - Security
- Maturity Evaluation
  - Critical Technical Parameters
    - Progress relative to "Growth Curve"
  - Incremental assessment plan
    - Operational Assessments
      - Observation of Operational Capability

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Capability Characterization Plan

Crosswalk : Performance, Measures & Activities

Line #	CA Requirement	Requirement *Language*	OCD Reference	System A	System B	System C	MS&A or T&E Activity *(examples)*	Master Schedule Event I.D.
1	**IFPM** *Integrated Function Performance Measure*			**CTP**	**CTP**	**CTP**	Predictive Analysis (combined single-system data)	***ID***
2	**IFPM** *Integrated Function Performance Measure*			N/A	**CTP**	**CTP**	Constructive M&S (multi-system)	***ID***
3	**IFPM** *Integrated Function Performance Measure*			**CTP**	N/A	**CTP**	HWIL (multi-system)	***ID***
4	**IFPM** *Integrated Function Performance Measure*			**CTP**	**CTP**	N/A	OITL / MITL (multi-system)	***ID***
5	**IFPM** *Integrated Function Performance Measure*			**CTP**	**CTP**	**CTP**	Live: Demo / Prototype (multi-system)	***ID***
6	**CTP** *Critical Technical Parameter*			**Value / Range**	N/A	N/A	HWIL (System-Level)	***ID***
7	**CTP** *Critical Technical Parameter*			N/A	**Value / Range**	N/A	HWIL (Integration)	***ID***

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Presenter Biography
BRYAN HERDLICK

BRYAN HERDLICK is a Ph.D. candidate at George Washington University in the Engineering Management and Systems Engineering curriculum. As a member of the senior professional staff at the Johns Hopkins University Applied Physics Laboratory, he assists the Naval Aviation Systems Command with the development of advanced capabilities and complex systems. Bryan is an INCOSE Certified Systems Engineering Professional with additional certification in U.S. Department of Defense Acquisition application (CSEP-Acq.). Bryan's academic background includes a BS in Electrical Engineering from the University of Dayton and a MS in Applied Physics from the Naval Postgraduate School. He is also a graduate of the U.S. Navy Test Pilot School and a distinguished graduate of the Naval War College. His collateral activities include supporting ABET on accreditation visits as a program evaluator volunteer and teaching Systems Engineering courses for the Johns Hopkins University Whiting School of Engineering.