Application of Model-Based Systems Engineering

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Agenda

- **Capstone Objective**
- **Overview of Q1 and Q2**
  - Team Organization
  - Execution & Scope
  - Research
  - Methodology
- **Results & Products**
  - Requirements
  - Functional Analysis
  - Architecture
  - Modeling and Simulation
 - *CORE*
- **Capstone Conclusions**

Capstone Objective

- **The Objective of this Project was to Develop a System Engineering (SE) Methodology for Creating Complex, Supportable System Architectures that:**
  - Utilize a Model Based Systems Engineering (MBSE) approach
  - Integrate Requirements Traceability
  - Implement Open Architecture (OA) and SPLs
  - Identify a structure which supports Combat System Software Reuse
  - Support early Integration of Supportability Requirements
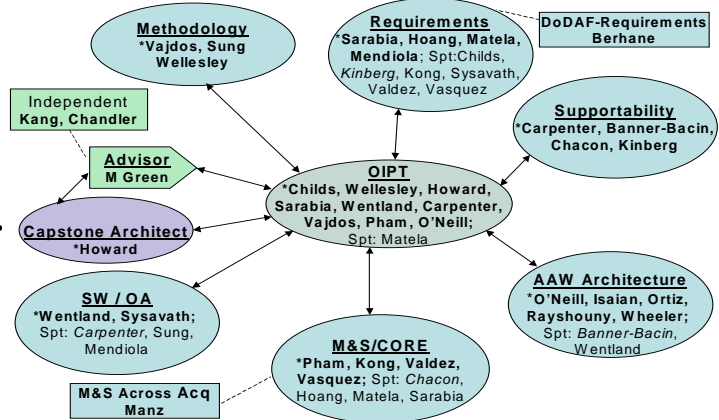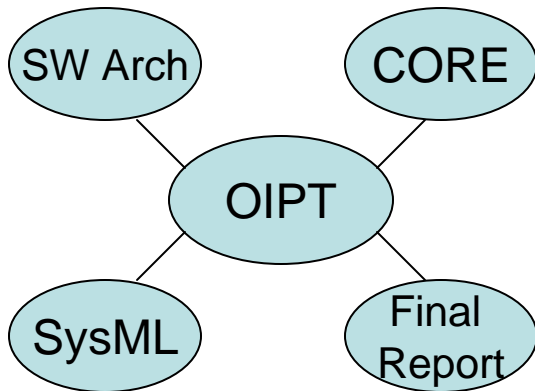 - Integrate DoDAF Artifacts with the Acquisition Requirements Process

Team Organization

IPT Structure Evolved with CAPSTONE Need
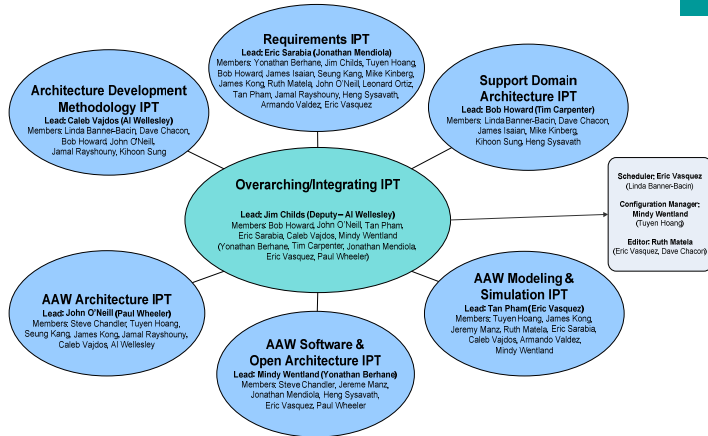
Q1 Structure based on key research objective

Q2 Structure based on process execution

Q3 Structure based on artifact development

Primary Research Topics

Research Areas	Research Artifacts Quantity
Open Architecture	14
Service Oriented Architecture	2
DoD Architecture Framework	8
Domain Analysis	6
Software Product Lines	8
Model Based Systems Engineering	23
Systems Engineering "VEE"	3
Software Reuse	6
Process System Architecture & Requirements Engineering	3
Concept of Operations	1
Software Architecture Types	7
Modeling & Simulation	3
Systems Modeling Language	13
ExtendSim Tools & Discrete Event Modeling	2
CORE	4
Reliability Theory	3
Supportability	7
Anti-Air Warfare (P_{RA}, etc.)	10
Total = 123	

Research focused on tools, methodologies, languages which could be applied to meet capstone objectives

Crucial areas of project were researched more extensively (OA, MBSE, SysML, and AAW)
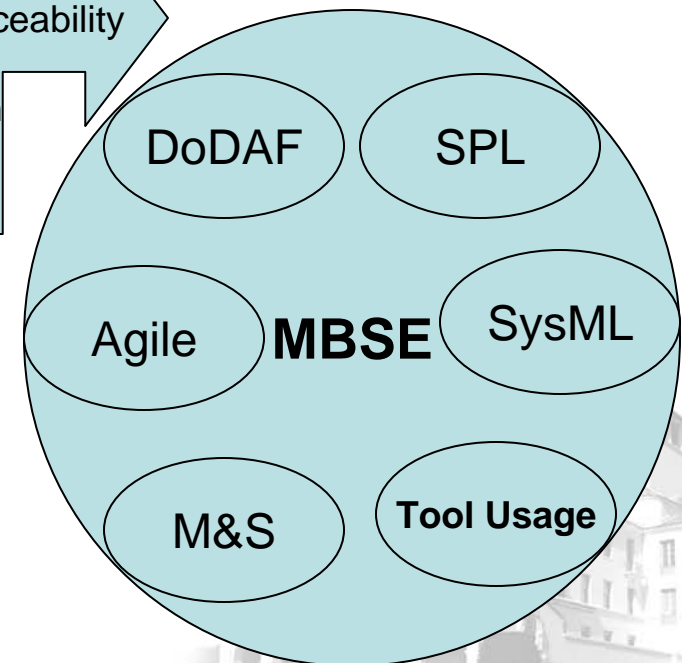
Research Application Methodology

Initial Research Findings

- No single process or solution

- M&S & Supportability limited

- Select correct modeling language

- DoDAF is not a process

- MBSE provides significant benefits
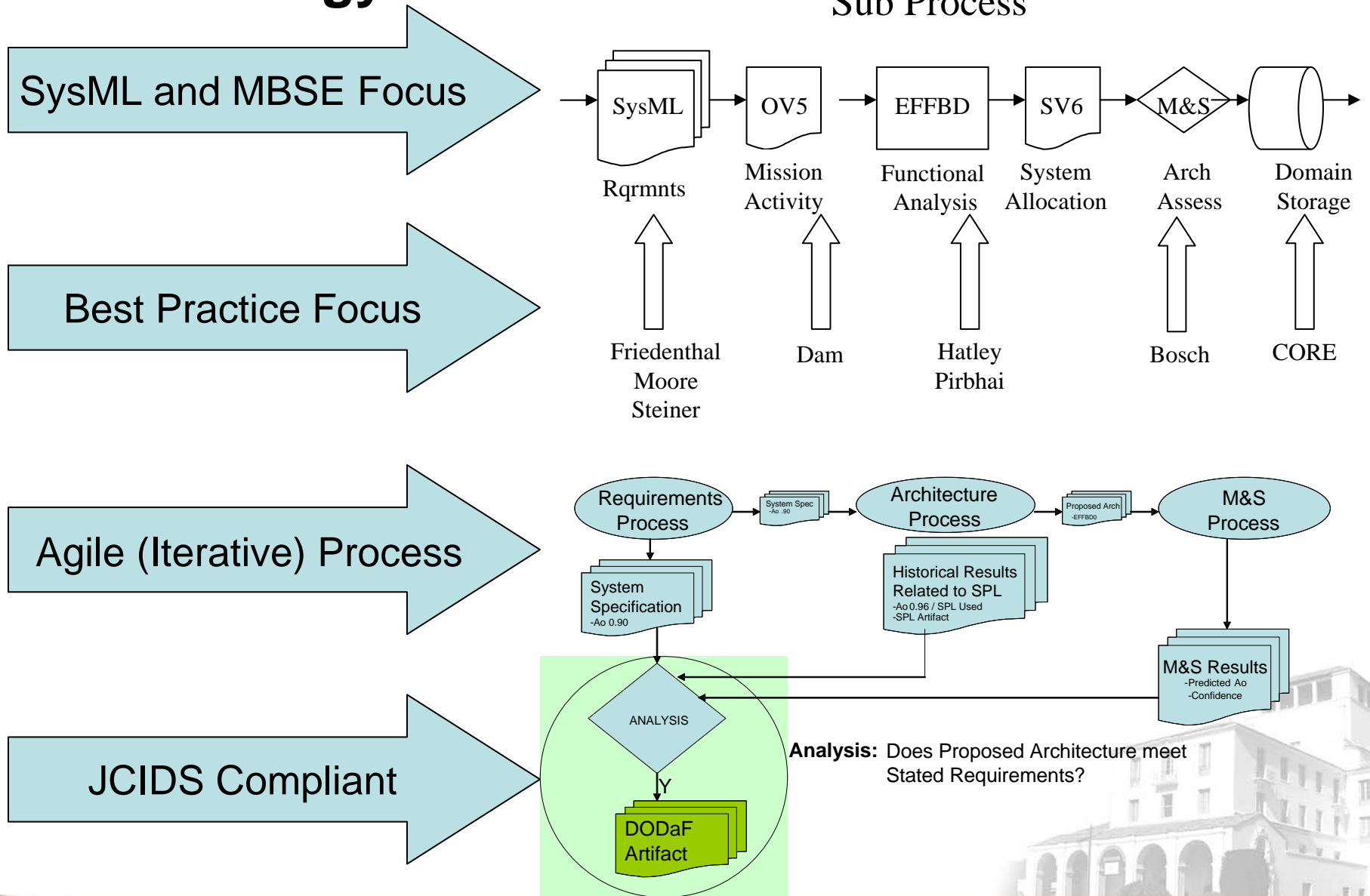
- Navy wrestling w/similar issues

Best Practice Defined for

MBSE
SPL Reuse
Language
Tool
Requirements Traceability
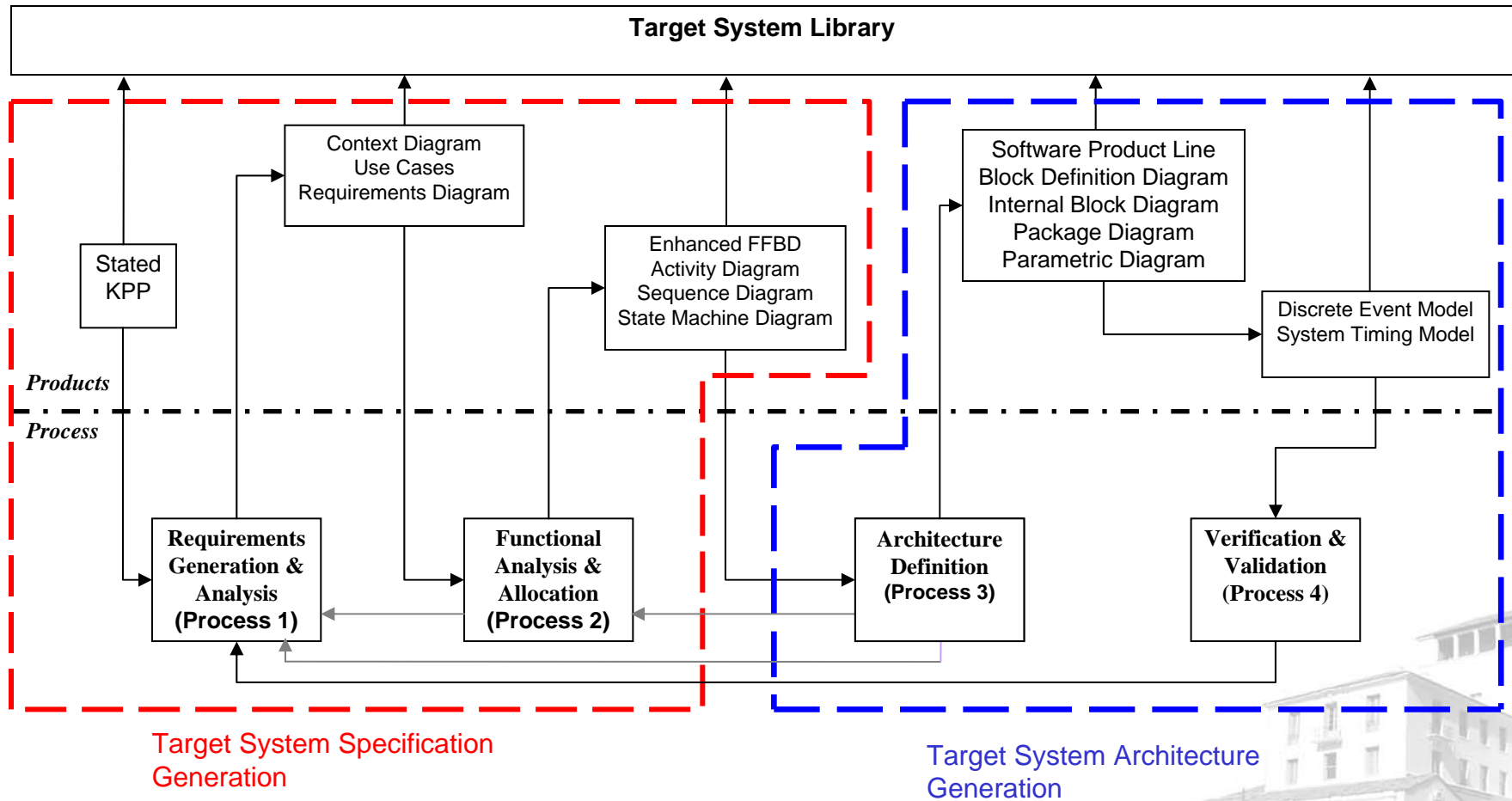M&S Application
Artifact Generation
V&V Methods
Library Structure

Proposed Methodology

DoDAF SPL

Agile **MBSE** SysML

M&S **Tool Usage**

Methodology Overview

Sub Process

SysML and MBSE Focus

SysML
Rqrmnts

OV5
Mission
Activity

EFFBD
Functional
Analysis

SV6
System
Allocation

M&S
Arch
Assess

Domain
Storage

Best Practice Focus

Friedenthal
Moore
Steiner

Dam

Hatley
Pirbhai

Bosch

CORE

Agile (Iterative) Process

Requirements
Process

System Spec
-Ao .90

Architecture
Process

Proposed Arch
-EFFBD0

M&S
Process

System
Specification
-Ao 0.90

Historical Results
Related to SPL
-Ao 0.96 / SPL Used
-SPL Artifact

M&S Results
-Predicted Ao
-Confidence

JCIDS Compliant

ANALYSIS

Y

DODaF
Artifact

Analysis: Does Proposed Architecture meet
Stated Requirements?

Defense Acquisition in Transition
6TH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

May 12-14, 2009
Monterey, CA

NPS
PRAESTANTIA PER SCIENTIAM
1909

Methodology Top Tier Process

Target System Library

Context Diagram
Use Cases
Requirements Diagram

Software Product Line
Block Definition Diagram
Internal Block Diagram
Package Diagram
Parametric Diagram

Stated
KPP

Enhanced FFBD
Activity Diagram
Sequence Diagram
State Machine Diagram

Discrete Event Model
System Timing Model

Products

Process

**Requirements
Generation &
Analysis
(Process 1)**

**Functional
Analysis &
Allocation
(Process 2)**

**Architecture
Definition
(Process 3)**

**Verification &
Validation
(Process 4)**

Target System Specification
Generation

Target System Architecture
Generation

Approach to Verify Methodology

- Use Methodology to Develop an AAW Mission Architecture

- Meet the following MOEs:
  - Self Defense
  - Limited Area Defense
  - Surveillance

Requirements Issues and Resolutions

- **SysML Tool Availability**
  - **No software license for proven tools**
  - **No formal training available for proven tools**

Independent Research
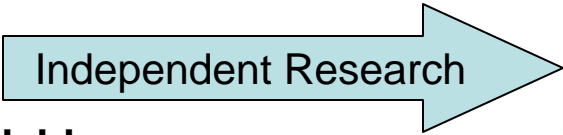
On-Line User Manuals

- **Baseline for Requirements**
  - **Schedule required, parallel development**

Interaction
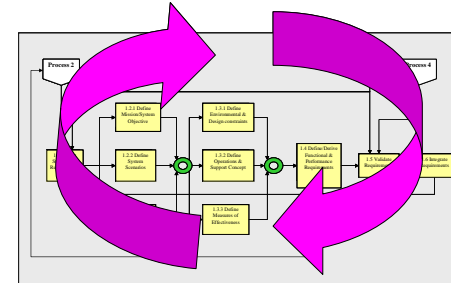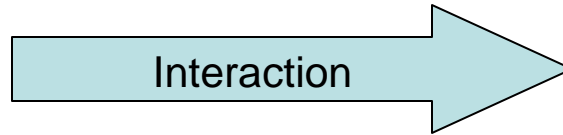
  - **Insufficient information to derive many of requirements needed for Parametric**

Target Track Geometry, Max # Intercepts @ CPA
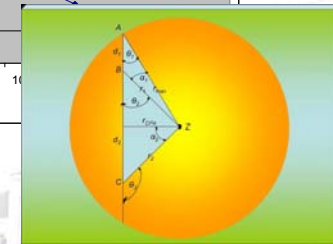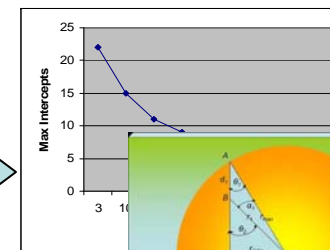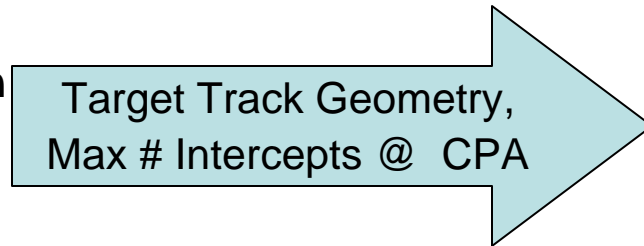
Requirements Results / Products

External Interface Requirements

SysML Context Diagram

Major Functions

SysML Use Case Diagram

Supportability Requirements

SysML Supportability Package
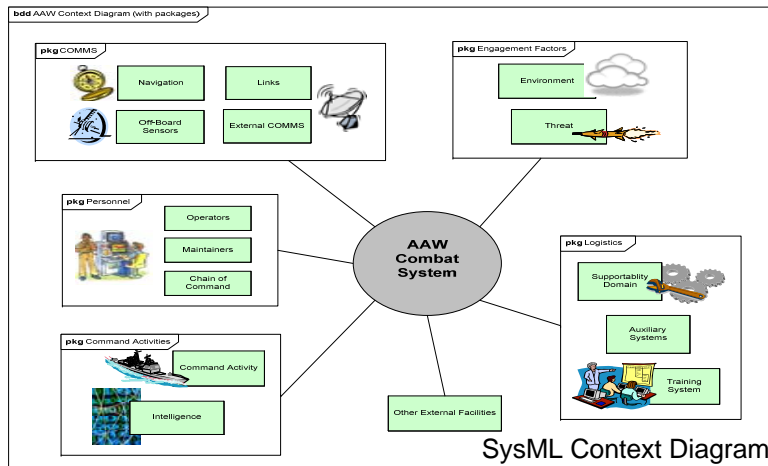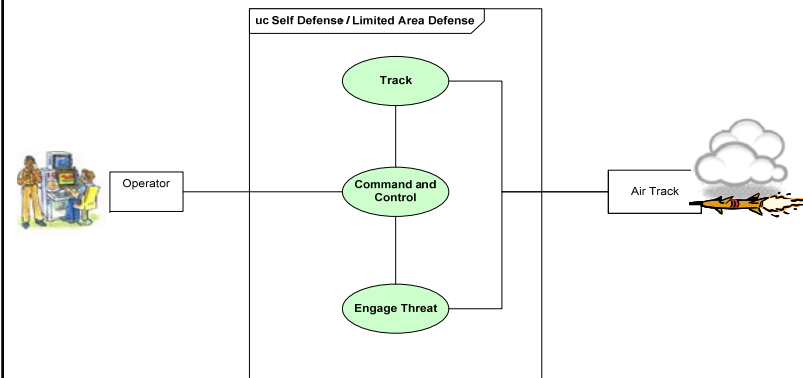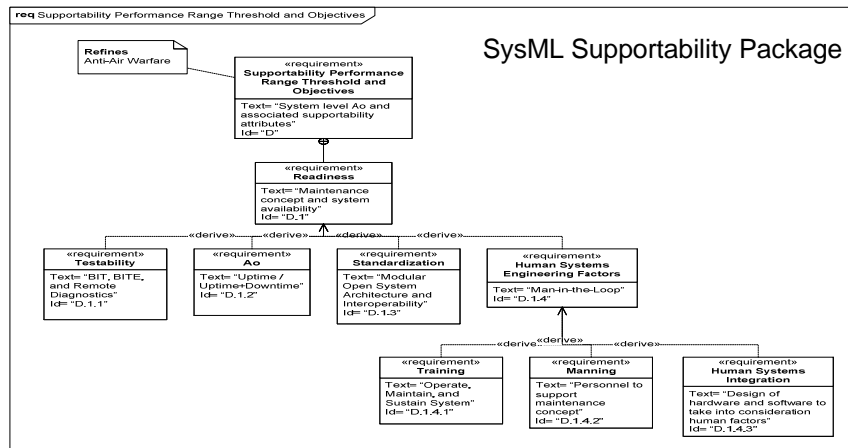
Traceability Achieved w/SysML

SysML Requirements Diagram
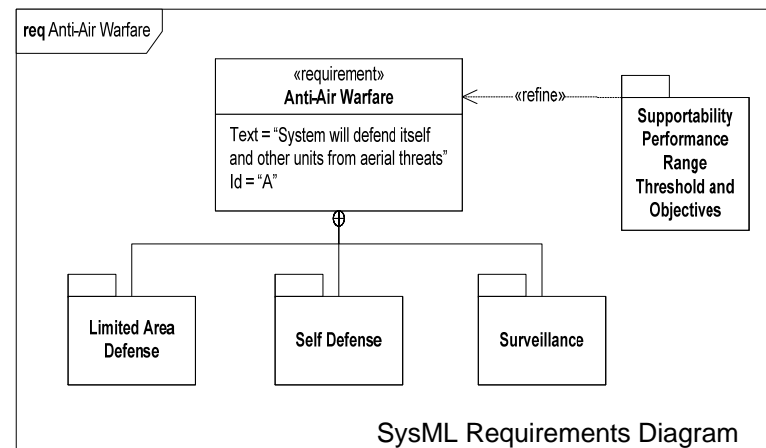
Requirements Summary

- Process Execution

  - Improved over time
  - Teams became more effective with experience

- Issues and Resolutions

  - Tools, KSAs and processes are not in place to lead requirements development on large complex systems
    - This Issue can be overcome to support PHD technical oversight and strategic objectives

- Artifacts

  - The process resulted in valid artifacts which support Capstone objectives

- Lessons Learned

  - Expand M&S Usage
    - Requirements Decomposition
    - Requirements Allocation
  - Understand Artifact Relationship
  - Maintain Tool
    - Traceability Establishment
    - Verification of Allocation

Functional Analysis Issues and Resolutions

- **Systems Engineering process to optimize allocation of functions**
    - **Deriving Software Requirements**
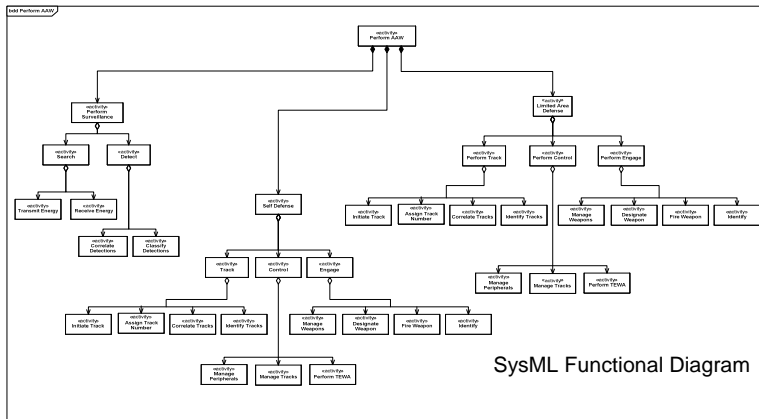   - **Tendency to map based on experience**
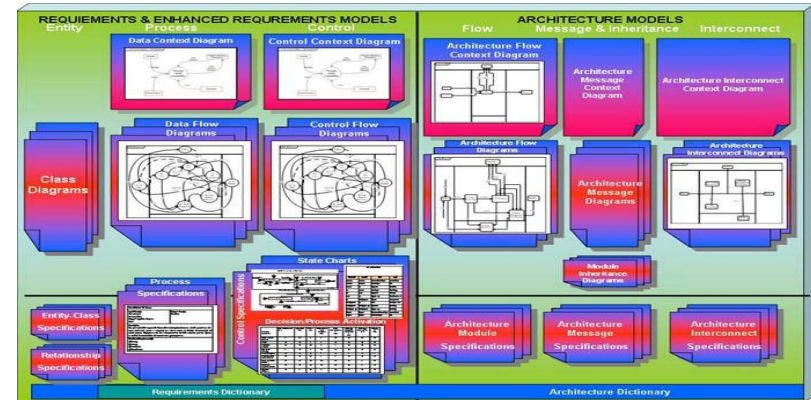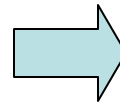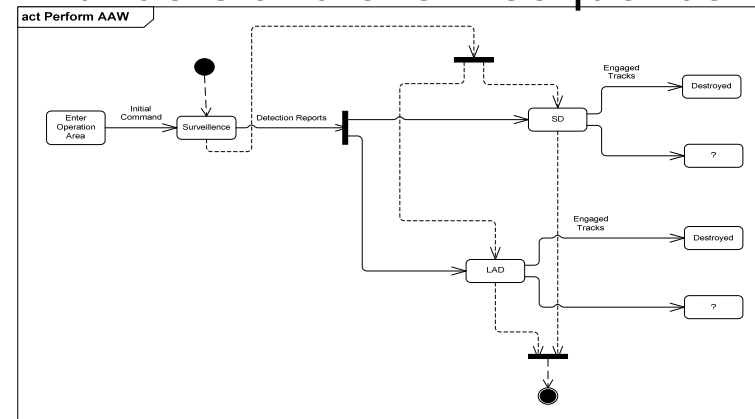

- **Common Domain and Functional Descriptions**

NTAs & UNTL
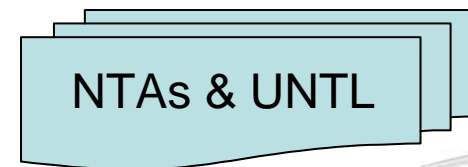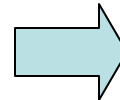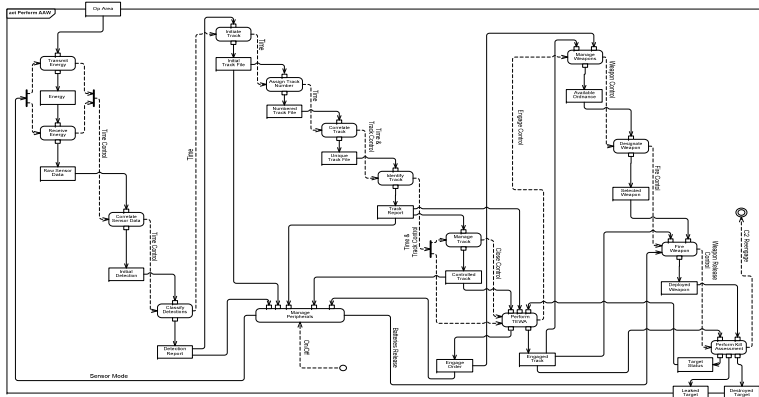
Functional Analysis Results / Products

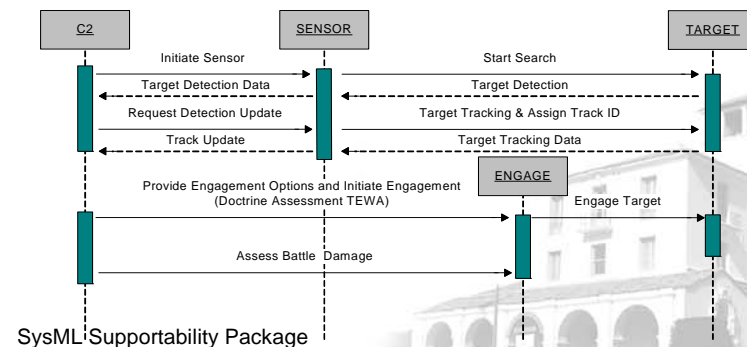## SysML traceability from requirements to functions

SysML Functional Diagram

Activity diagram used to understand event sequence

EEFBD provided control and timing relationships



Sequence diagram provides graphical representation


SysML Supportability Package

Functional Analysis Summary

- **Process Execution**
    - Hatley Pirbhai method was integrated with SysML language to provide a sound SE approach with a MBSE format

- **Issues and Resolutions**
    - Artifact development challenged by lack of inherent tools to develop, update and apply M&S to optimize design and verify traceability

- **Artifacts**
    - Provide powerful depictions for communicating and analysis for design and development

- **Lessons Learned**
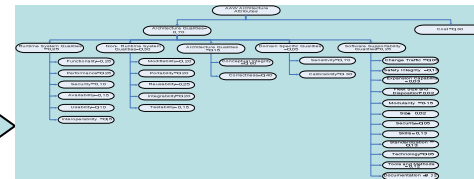   - Process is an iterative loop in learning a flexible tool set
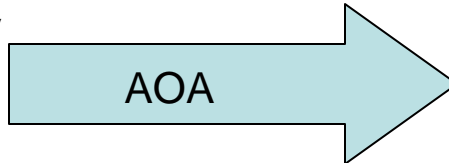   - Ensure SME Availability
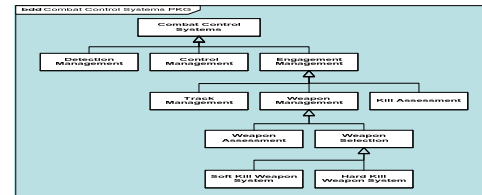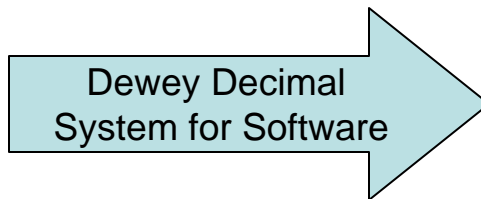
Architecture Issues and Resolutions
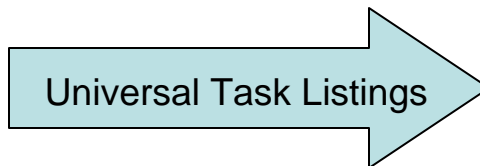
- Lack of Core Knowledge in Architecture Development Process

  H-P Method
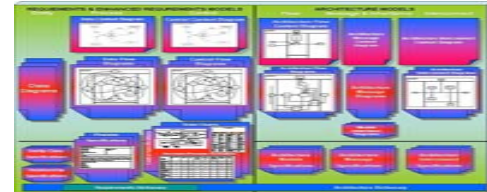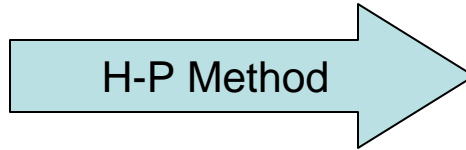
- Software Architecture Quality Attributes not fully defined or measurable

  AOA

- Lack of DoD Common SPL Library

  Dewey Decimal System for Software

- Lack of Common Task & Function Description

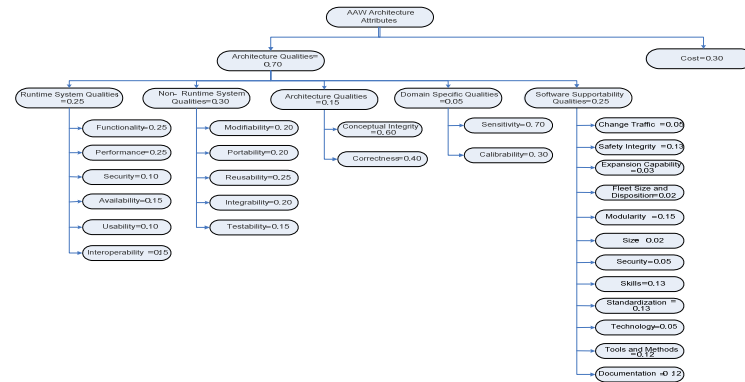 **Universal Task Listings**
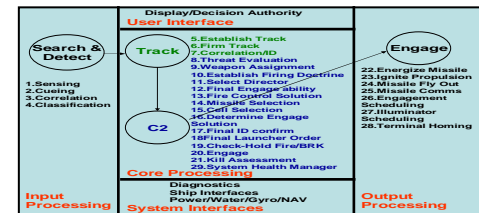
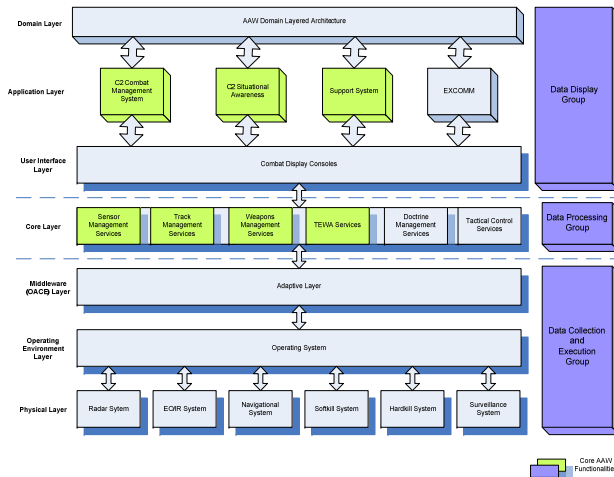# Architecture Results / Products

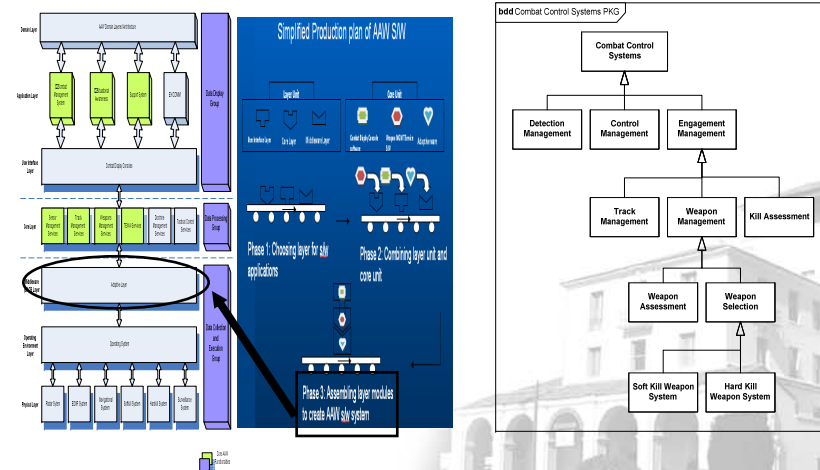## AAW System Specifications
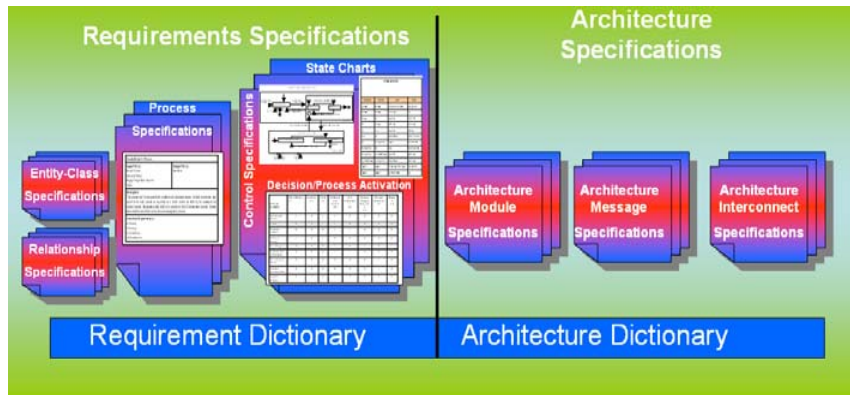
Objective Hierarchy to Assess Arch

Software Architecture

AAW SPL Library Framework

Architecture Summary

- **Process Execution**
  - SysML
  - Hatley-Pirbhai / Bosch processes provided for:
    - allocating and optimizing functions to architecture

- **Issues and Resolutions**

  - Lack of Navy structure will continue to create "stand-alone" solutions

- **Artifacts**
  - Hatley-Pirbhai System Specifications (Limited)
  - AAW Software Architecture framework
  - Software Product Line (SPL) framework

- **Lessons Learned**
  - Solutions have been proposed by various leads within Navy (C4I/CS/HM&E) on OA and SPL
    - **Not Domain Based; Software Reuse still in future**
    - **Need M&S base to strategize early**
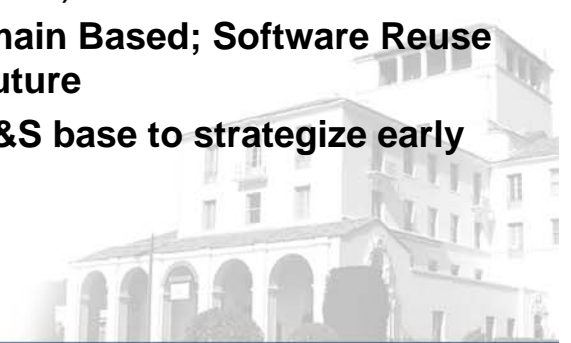
M&S Issues and Resolutions

- **NMCI Limitations**
  - VPN Connection to NPS Virtual Lab
    → Non-NMCI →
  - License Issue
    → DEMO Version →

- **Extend Training**
  - Lack of Experience with Extend
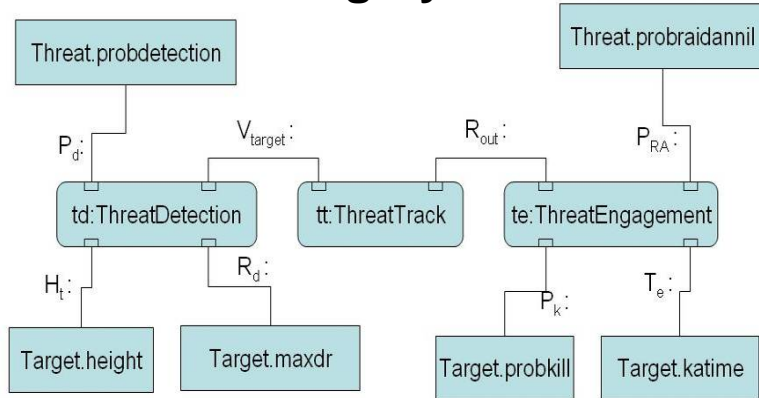   → User's Guide Tutorials →

- **Unrealistic Input Parameters**
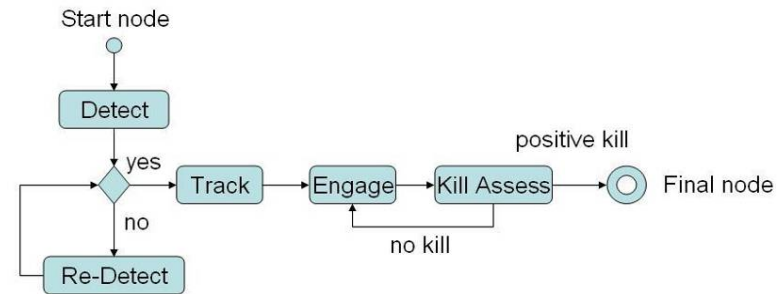 → Revised Requirement with Stakeholder →

M&S Results / Products

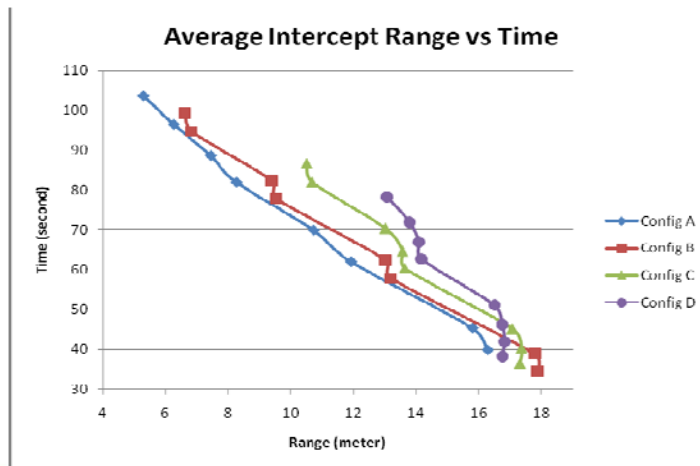## Requirements Traceability Using SysML

SysML Parametric Diagram
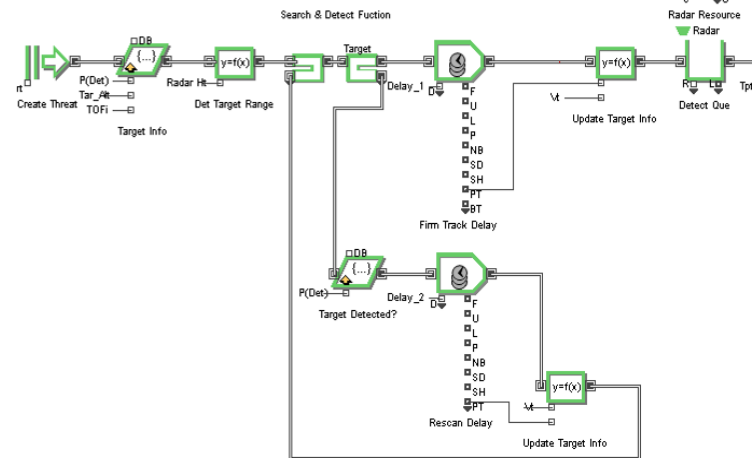
Model Expansion Supported by Functional Architecture

High Level Model

Data Analysis

Model Derived from Architecture

Search & Detect Sub-Function
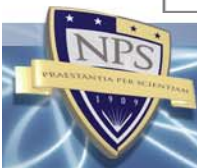
M&S Summary

- **Process Execution**
  - M&S was used to identify feasibility, configuration performance differences, and verify Requirements

- **Issues and resolution**
  - Parallel efforts required adaptable models that could be updated as Systems Engineering artifacts are created

- **Artifacts**
  - Physical modeling and P_{RA} simulation used to verify optimal configuration

- **Lessons Learned**
  - M&S provides valuable insight into architecture design, requirements decomposition, and other areas which are outside the traditional ISEA use

Capstone Conclusions
Major Findings

- **MBSE was Successful in Communicating Requirements and Information across Disciplines**

- **Best Process Integrates "best practices" from Language, Tools, and Processes**

- **Integration of Logisticians & Engineers improved Product Quality and inclusion of Supportability in Design**

- **Tools for Verification and Validation of Engineering Artifacts**

- **M&S Application extends beyond Operation Scenarios**

Capstone Conclusions Recommendations

- Develop Logisticians to support early acquisition
    - Logisticians demonstrated KSAs to work in SE Concept and Development
- Establish Domain-Specific Components/Quality Attributes
    - Identify QA Weighting System to Balance Sustainment and Performance by Domain
- Develop SPL Library Criteria and Characteristics
    - Define Data Tags required to assess SPL Reusability
- Continue Effort to V&V Methodology
    - Continuing System Decomposition based on Methodology
    - Execution of Methodology to Develop S/W, H/W and Interface Components will result in Additional Findings/Lessons Learned
- Leverage Methodology to Estimate Life Cycle Cost and RAM through M&S
    - Use Artifacts to Support Early LCCE and RAM KPP reporting Requirements

MSSE/MSSEM Program Conclusions

- Value added by having Engineers and Logisticians combined
  - Learned to "understand the languages"
  - Exposure to process increases ability to support
- Program directly contributes to PHD Strategic Goals
  - Provides KSAs to work "early acquisition"
  - Improves understanding of Systems Engineering process to sustain oversight
  - Increases Product Support Integrator (PSI) capability by increasing knowledge across sub-elements (Engineering, Logistics, T&E, Acquisition)
- Follow on Planning needed to minimize "Fire and Forget"