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
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).

### Primary Research Topics

<table>
<thead>
<tr>
<th>Research Areas</th>
<th>Research Artifacts Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Architecture</td>
<td>14</td>
</tr>
<tr>
<td>Service Oriented Architecture</td>
<td>2</td>
</tr>
<tr>
<td>DoD Architecture Framework</td>
<td>8</td>
</tr>
<tr>
<td>Domain Analysis</td>
<td>6</td>
</tr>
<tr>
<td>Software Product Lines</td>
<td>8</td>
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<tr>
<td>Model Based Systems Engineering</td>
<td>23</td>
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<tr>
<td>Systems Engineering “VEE”</td>
<td>3</td>
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<tr>
<td>Software Reuse</td>
<td>6</td>
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<tr>
<td>Process System Architecture &amp; Requirements Engineering</td>
<td>3</td>
</tr>
<tr>
<td>Concept of Operations</td>
<td>1</td>
</tr>
<tr>
<td>Software Architecture Types</td>
<td>7</td>
</tr>
<tr>
<td>Modeling &amp; Simulation</td>
<td>3</td>
</tr>
<tr>
<td>Systems Modeling Language</td>
<td>13</td>
</tr>
<tr>
<td>ExtendSim Tools &amp; Discrete Event Modeling</td>
<td>2</td>
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<tr>
<td>CORE</td>
<td>4</td>
</tr>
<tr>
<td>Reliability Theory</td>
<td>3</td>
</tr>
<tr>
<td>Supportability</td>
<td>7</td>
</tr>
<tr>
<td>Anti-Air Warfare (P_RA, etc.)</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>123</strong></td>
</tr>
</tbody>
</table>


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 Artifacts
- Generation V&V Methods
- Library Structure

Proposed Methodology

- DoDAF
- SPL
- Agile
- SysML
- MBSE
- M&S
- Tool Usage
Methodology Overview

SysML and MBSE Focus

Best Practice Focus

Agile (Iterative) Process

JCIDS Compliant

Analysis: Does Proposed Architecture meet Stated Requirements?

Requirements Process

Architecture Process

M&S Process

System Specification

Proposed Architecture

Historical Results Related to SPL

SPL Artifact

DODaF Artifact

ANALYSIS

May 12-14, 2009
Monterey, CA
Methodology Top Tier Process

Target System Library

1. Stated KPP
2. Requirements Generation & Analysis (Process 1)
3. Functional Analysis & Allocation (Process 2)
4. Architecture Definition (Process 3)
5. Verification & Validation (Process 4)

Discrete Event Model
System Timing Model

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

Enhanced FFBD
Activity Diagram
Sequence Diagram
State Machine Diagram

Context Diagram
Use Cases
Requirements Diagram

Target System Specification
Generation

Target System Architecture
Generation

Products
Process

Requirements
Generation &
Analysis
(Process 1)

Functional
Analysis &
Allocation
(Process 2)

Architecture
Definition
(Process 3)

Verification &
Validation
(Process 4)
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

- **Baseline for Requirements**
  - Schedule required, parallel development
  - Insufficient information to derive many of requirements needed for Parametric

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**Independent Research**

**On-Line User Manuals**

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**Interaction**

**Target Track Geometry, Max # Intercepts @ CPA**

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**Defense Acquisition in Transition**

6th Annual Acquisition Research Symposium

May 12-14, 2009
Monterey, CA
Requirements Summary

• Process Execution
  – Improved over time
  – Teams became more effective with experience

• Artifacts
  – The process resulted in valid artifacts which support Capstone objectives

• 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

• 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
Functional Analysis Results / Products

SysML traceability from requirements to functions

Activity diagram used to understand event sequence

Sequence diagram provides graphical representation

EEFBD provided control and timing relationships

SysML Functional Diagram

SysML Supportability Package

Sensor

Target Detection

Initiate Sensor

Provide Engagement Options and Initiate Engagement

(Target Detection Data)

Request Detection Update

Target Detection

Target Tracking & Assign Track ID

Track Update

Target Tracking Data

Assess Battle Damage

Engage Target

Start Search

Assessment

Detection Report

Sensor

Target

C2

SysML Supportability Package
### Functional Analysis Summary

<table>
<thead>
<tr>
<th>Process Execution</th>
<th>Issues and Resolutions</th>
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<tbody>
<tr>
<td>- Hatley Pirbhai method was integrated with SysML language to provide a sound SE approach with a MBSE format</td>
<td>- Artifact development challenged by lack of inherent tools to develop, update and apply M&amp;S to optimize design and verify traceability</td>
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<table>
<thead>
<tr>
<th>Artifacts</th>
<th>Lessons Learned</th>
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<tbody>
<tr>
<td>- Provide powerful depictions for communicating and analysis for design and development</td>
<td>- Process is an iterative loop in learning a flexible tool set</td>
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<tr>
<td></td>
<td>- Ensure SME Availability</td>
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</tbody>
</table>
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

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Architecture Summary

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

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

- **Issues and Resolutions**
  - Lack of Navy structure will continue to create “stand-alone” solutions

- **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
  - License Issue

- Extend Training
  - Lack of Experience with Extend

- Unrealistic Input Parameters

Non-NMCI

DEMO Version

User’s Guide Tutorials

Revised Requirement with Stakeholder
M&S Results / Products

Requirements Traceability Using SysML

Model Expansion Supported by Functional Architecture

Model Derived from Architecture

Data Analysis

Average Intercept Range vs Time

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M&S Summary

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

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

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

- 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”