Approach to Achieve Benefits of Modularity in Defense Acquisition (WRT-1002)

Sponsor: ODASD(SE)

Presented on behalf of research team by:
Dr. Cesare Guariniello

12th Annual SERC Sponsor Research Review
HOSTED VIRTUALLY ON: November 18, 2020
www.sercuarc.org
Four-year effort: RT-163, RT-185 and WRT-1002, under SERC sponsorship

Dr. Daniel DeLaurentis, PI
Professor – School of Aeronautics and Astronautics – Purdue University
Director – Institute for Global Security and Defense Innovation
Chief Scientist of the SERC

Dr. Cesare Guariniello
Research Scientist – School of Aeronautics and Astronautics
Purdue University

Dr. Jean (Charles) Domercant
Senior Research Engineer
Georgia Tech Research Institute

Mr. Thomas McDermott, Jr.
Deputy director – Systems Engineering Research Center
Stevens Institute of Technology

Dr. Gary Witus
Associate professor – Industrial and Systems Engineering
Associate director for student programs – Anderson Institute
Wayne State University
“The” problem: limitations of current approach in multi-domain battle scenario

- Complexity
  - Size
  - Interactions
  - Dynamics

- Trade space for modularity
  - Mission level, SoS level, system level
  - Competing metrics

- Uncertainty
  - Performance/cost
  - Future missions
  - Gradual development

In this context, DOD acquisition challenges:
- Affordably address emerging threats
- Component obsolescence
- Planned technology upgrade for tightly coupled, highly integrated systems and dynamic missions
Why Modular Open Systems Approach (MOSA)?

- MOSA encourages adoption of modularization and open architectures
  - Speed of delivery
  - Flexibility
  - Cost reduction

- Findings from previous research tasks:
  - Modularity is not a goal but a means to achieve benefits
  - “Doing good MOSA” is not only about the architecture but about readiness of organizations

- Objectives
  - Develop strategies and tools to be successful in MOSA ecosystem
  - Identify guidelines for implementation
  - Quantify the benefits
  - Support both technical and managerial aspects
Identify user needs: a MOSA workshop

- **2017 Workshop** with government, military, academia, and industry suggested needs and requirements
- **Interviews** to Program Managers to learn about their perspective

**Key findings:**
- MOSA is a means to achieve benefits
- Early stage acquisition process key to modularity and openness
- Early support mechanisms in place
- Need to address both managerial and technical needs
- Organization needs to be ready to deal with the solution
- Tools to assess consequences of modularization choices
Prototype Decision Support Framework (DSF)

Chose to pursue cascading matrices to create a visual analysis of how the inputs translate to the outputs throughout the program lifecycle.

Established a potential path forward for data collection and case studies.

Translate knowledge from AoA, JCIDS, OSA contract guidebook, and case studies into cascading dependencies, PM guidance document and prototype software.
Based on lessons learned, contains case study summaries related to early stage lifecycle implications on MOSA:

- Early stage acquisitions SE
- Due diligence across each segment of the acquisition lifecycle
- …need to consider their (modular and open solution) impact on the organization that’s employing it – Is the organization using this solution ready to deal with it?
- Having appropriate systems engineering artifacts (e.g. MBSE) at early stages
- It is never too early to think about how contracting can support MOSA objective
Objectives of WRT-1002 MOSA research

- Building upon previous efforts, refine MOSA Decision Support Framework (DSF)
  - Quantitative analysis, SoS-based and focused on cost, risk, schedule trade-offs
  - Qualitative analysis, based on cascading matrices and organizational structure
- Translate knowledge from specific programs into functional features of DSF
- Explore tradeoffs between metrics of interest against various strategies
- Validate and verify the effectiveness of prototype DSF

![Diagram of MOSA Decision Support Framework (DSF)](image-url)
Continuous learning

- Interaction with stakeholders, analysis of historical data, case studies
  - MOSWG (MOSA pillars by Naval Information Warfare Center, NDIA guidelines)
  - VICTORY program (standard electronic systems architecture for ground vehicles)
  - MBSE for MOSA (including lessons learned from RT-187, presented at CSER 2020)
  - Open Architecture Assessment Tool (OAAT)

Dai, Guariniello, and DeLaurentis, *Implementing a MOSA Decision Support Tool in a Model-Based Environment*, CSER 2020
Decision Support Framework (DSF) 2.0 – case study

- Multi-domain battle scenario. Requirements based on Mission Engineering
  - RPO to identify alternative sets / architectures
  - SODA for analysis of criticality
  - Cascading matrices of capabilities
  - Analysis of applicable MOSA principles

- Useful to study different future missions (flexibility), as well as modular vs. non-modular sets / architectures

Example of problem setup for RPO. Mission scenarios require SoS capabilities, provided by systems that also have I/O support requirements and associated costs and uncertainty.

<table>
<thead>
<tr>
<th>No.</th>
<th>System Type</th>
<th>System Name</th>
<th>Transport Range</th>
<th>Transport Capacity</th>
<th>System Capabilities</th>
<th>Support/System Capability Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air Systems</td>
<td>B-17 Flying Fortress</td>
<td>0</td>
<td>0</td>
<td>6000</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>C-47</td>
<td>0</td>
<td>0</td>
<td>1800</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Infantry Pavilion</td>
<td>10</td>
<td>1</td>
<td>1445</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>4</td>
<td>Ground</td>
<td>M-4 Sherman</td>
<td>155</td>
<td>121</td>
<td>0</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>5</td>
<td>Systems</td>
<td>TARDEC Artillery Module</td>
<td>100</td>
<td>1750</td>
<td>0</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>TARDEC Personnel Module</td>
<td>150</td>
<td>0</td>
<td>300</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Refuel Depot</td>
<td>0</td>
<td>0</td>
<td>10000</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Re-supply Depot</td>
<td>0</td>
<td>0</td>
<td>10000</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Assault Kit, Machine Destroyer</td>
<td>0</td>
<td>0</td>
<td>10000</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Landing Ship, Tank (LST)</td>
<td>0</td>
<td>0</td>
<td>10750</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>11</td>
<td>Space</td>
<td>Wideband Global Satellite Communication Satellite (WGS)</td>
<td>0</td>
<td>0</td>
<td>10000</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>General Personnel</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Cost: $3,399,600.00 N</td>
</tr>
</tbody>
</table>
**Input to DSF**

In current version, input through spreadsheet

<table>
<thead>
<tr>
<th>Systems</th>
<th>Support requirements</th>
</tr>
</thead>
</table>

- **System capabilities**
- **Cost**
- **Modular properties**
- **Uncertainty**

**Systems**
- [List of systems]

**Support requirements**
- [List of requirements]

**Cost**
- [Cost details for each system]

**Modular properties**
- [Properties of each system]

**Uncertainty**
- [Uncertainty details for each system]
SoS capabilities as function of System capabilities

Compatibility and selection constraints

Conditionally required systems

<table>
<thead>
<tr>
<th>No.</th>
<th>SoS-Capability</th>
<th>SC1 = Attack Air - Ground</th>
<th>SC2 = Defend Air Against Ground</th>
<th>SC3 = Mobility Air</th>
<th>SC4 = Communication</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air Superiority</td>
<td>1, 2</td>
<td>3, 4</td>
<td>5, 6</td>
<td>7</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>Naval Superiority</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tactical Bombardment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Land Seizure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Land Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Reconnaissance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

System-Capability Indices

1 Air Superiority 1,2 3,4 5,6 7 ...
2 Naval Superiority 7 ...
3 Tactical Bombardment 5,6 7 ...
4 Land Seizure 5,6 7 ...
5 Land Control 5,6 7 ...
6 Reconnaissance 5,6 7 ...

1 Air Superiority 1,2 3,4 5,6 7 ...
2 Naval Superiority 7 ...
3 Tactical Bombardment 5,6 7 ...
4 Land Seizure 5,6 7 ...
5 Land Control 5,6 7 ...
6 Reconnaissance 5,6 7 ...

Compatibility and selection constraints

Conditionally required systems

SoS capabilities as function of System capabilities

SSRR 2020 November 18, 2020 12
DSF GUI: opening window and main window

Selection of database / scenario

Selection of SoS capabilities for optimization, risk aversion and budget limit instances
DSF results / 1: Portfolios and Pareto fronts

Optimal portfolios and selection for further analysis

Pareto front of cost vs. performance for a given level of risk aversion
DSF results / 2: Network representations of portfolios

Systems and required support

Subset of systems that provide transport capacity
DSF results / 3: cascading matrices

System capabilities to SoS capabilities

System capabilities to systems

Systems to SoS capabilities
DSF results / 4: SODA analysis of criticalities

Systems Operational Dependency Analysis (SODA) Disruption Impact Matrix (DIM). Impact of disruptions of various systems on other systems and SoS capabilities.
DSF results / 5: analysis of applicable MOSA principles

Systems and corresponding benefit from MOSA principles

Graphical representation of systems and MOSA principles from which they can benefit
Comments on modularity in DSF

• Modularity currently from database
  — Includes lessons learned from PM guidance document
  — Includes constraints about support systems
  — Includes cost and performance

• To be added: further external information (managerial requirements, cost of modularity), internal analysis (for example, number of feasible architecture that share part of the same modular option)
Conclusions

MOSA research highlighted needs:
• Include MOSA considerations upfront
• Evaluate which systems / programs can benefit from MOSA
• Tools to **assess performance** in complex scenarios and trade-off **cost and risk** under different choices for modularity

**Decision Support Framework** development:
• Generate portfolios, given database of systems
• Generate pareto fronts of cost vs. performance for different level of risk aversion
• Further analysis:
  — Cascading matrices for qualitative assessment
  — Systems Operational Dependency Analysis (SODA) for operational criticalities
  — MOSA analysis for systems that can benefit from application of MOSA principles
  — Graphical representation and analysis of support requirements

**Transition plan**
• Developing and refining DSF in other projects
• Interest from MOSWG
• Dissemination of the work to identify potential partners for further case studies