Designing & Evaluating Agile C2 Systems Based on Service Oriented Architectures*

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Outline

- Introduction & Background
- SOA Environment
- SOA Federation Structure
- Architecting Process
  - Architecture Design
  - Analysis & Evaluation
  - Architecture Deployment
- Case Study
  - Airborne Theater Ballistic Missile Interceptor System (ATIS)
- Conclusions & Future Work
A key to Command and Control (C2) agility is EFFECTIVE information sharing.

DoD defined a set of concepts, objectives and strategies to achieve Net-Centric Operations (NCO)

- Concepts
  - Populate Net-Centric Environment (NCE).
  - Utilize the Net-Centric Environment.
  - Accommodate un-anticipated users.
  - Promote the use of Communities of Interest (COI).
  - Support shared infrastructure.

- Strategies
  - Net-Centric Data Strategy.
  - Net-Centric Services Strategy.

DoD views architectures as the mechanism for designing solutions to transform to NCO

DoD.AF v.1.5 is focused on data centricity and uses the Service Oriented Architecture (SOA) paradigm as a key enabler for implementing NCO.
Introduction & Background (2)

- DoDAF v.1.5: All View (AV), Operational View (OV), Systems & Services View and Technical View
- How to construct an Event Driven Service Oriented Architecture compliant to DoDAF v1.5?
- The architecture (SOA) should:
  - Net-Centric Concepts
    - Populate NCE with new capabilities
    - Utilize existing NCE capabilities
    - Accommodate un-anticipated users
    - Promote the use of COI
    - Support shared infrastructure
  - Net-Centric Data Strategy
    - Make data visible, accessible, understandable, and trusted
  - Net-Centric Services Strategy
    - Provide and consume services from the NCE, govern these services and their infrastructure, and monitor and manage them

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SOA Federation Environment

Service Layer
- Service Containers
- Service
- ESB
- Registry
- Orchestration
- MOM
- Supervisor

Service Layer
- Business Process n
- Business Process 2
- Business Process 1

Operational Layer
- SOA Federation

Physical Layer
- Network of computers

System Architectures Laboratory
• The concept of **Communities of Interest (COI)** will be used to enable dynamic federation with pre-defined or un-anticipated users.
• Architecture Design phase: Produce DoDAF v.1.5 products
• Analysis & Evaluation phase:
  – Synthesize the executable model (EM).
  – Use it to evaluate and verify the architecture.
  – Reflect corrections or changes back in the DoDAF products
  – Compute Measures of Performance and Measures of Effectiveness of the architecture.
• Architecture Deployment phase: new processes will trigger the design process again
• Based on the OO approach introduced by Wagenhals et. al

• Additional sources of information needed:
  1) Information about existing COIs and the services they expose
  2) Information about architectures of systems implementing capabilities that might be leveraged by the new architecture
  3) Access to existing Net-Centric Enterprise Services (NCES) currently available through the Net-Centric Environment
- A dynamic model of the business services and processes is built using CPN Tools
- Scenarios are defined to evaluate the logical and behavioral aspects of the architecture
- Formal analysis of system properties (Reachability, Boundedness, Liveness, etc...) is conducted
- State Space analysis to detect errors and unwanted behavior is carried out
- Corrections and changes are reflected back to the architecture description
Analysis & Evaluation (2)

Performance Prediction & Evaluation

- Extract and Insert Processing Delays
- Evaluate Timed CPN

Behavioral & Logical Evaluation

- Build Operational View Executable Model
- Evaluate CPN

Changes

OVs, SVs

SVs

MOPs, MOEs
Architecture Deployment

- Deployment phase: the architecture is instantiated and deployed to accomplish its missions and business objectives

- New business processes or changes to existing ones as a result of a SOA instance being deployed should trigger an architecture review

- This requires maintaining and calibrating the executable model of the architecture after deployment to support such exploration
Case Study: Airborne Theater Ballistic Missile Interceptor System (ATIS)

- Operational Concept graphic (OV-1): shows main operational nodes and Net-Centric Environment (NCE) support
Case Study (2)

• **Main objectives**
  – *Determine if the operational concept can be made to work.*
  – *Assess the impact of evolving this system into a federated SOA,*
  – *Determine how to make its business services or their composition* (business processes) *accessible by anticipated and un-anticipated users*

• **Assumptions:**
  – Two COIs:
    • Ballistic Missile Response COI
    • Intelligence, Surveillance, and Reconnaissance (ISR) COI
  – A Global Ballistic Missile Warning (GBMW) Service is deployed and is published through the Ballistic Missile Response COI
  – Net-Centric Enterprise Services (NCES) and capabilities are available and accessible. “e.g. Discovery, Messaging, Mediation Services“

*Business processes are composed of multiple business services*
# ATIS Business Services & Processes

<table>
<thead>
<tr>
<th>Services</th>
<th>System Node</th>
<th>Business Process Name</th>
<th>External Anticipated User</th>
<th>External Un-anticipated User</th>
</tr>
</thead>
<tbody>
<tr>
<td>EngageOrder</td>
<td>ATIS Command</td>
<td>DetectThreatBP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DetectThreat</td>
<td>ATIS Command</td>
<td>EngageThreatBP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EngageThreat</td>
<td>ATIS Command</td>
<td>KillThreatBP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KillThreat</td>
<td>ATIS Command</td>
<td>ATISBP</td>
<td>GBMWS</td>
<td>BMR COI</td>
</tr>
<tr>
<td>SD</td>
<td>ATIS Radar</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TrackRed</td>
<td>ATIS Radar</td>
<td>-</td>
<td>ISR COI</td>
<td></td>
</tr>
<tr>
<td>TrackBlue</td>
<td>ATIS Radar</td>
<td>-</td>
<td>ISR COI</td>
<td></td>
</tr>
<tr>
<td>AssessKill</td>
<td>ATIS Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TPRreport</td>
<td>ATIS Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control</td>
<td>ATIS Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## ATIS Scenario Profile

### Input Variables (Parameters)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of TBMs</td>
<td>Total number of TBMs launched by adversary (fixed).</td>
<td>10</td>
</tr>
<tr>
<td>TBM Inter-arrival</td>
<td>Time interval between TBM arrivals.</td>
<td>0, 25, 50, 75, 100 (seconds)</td>
</tr>
<tr>
<td>Number of Interceptors</td>
<td>Total number of ATIS Interceptors.</td>
<td>3, 4, 5</td>
</tr>
</tbody>
</table>

### Output Variables (Measures of Performance – MOPs)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Response Time</td>
<td>The average time between the ATIS detecting the TBM until the TBM is engaged.</td>
<td>&lt;= 400 seconds</td>
</tr>
<tr>
<td>Number of Leakers</td>
<td>Total number of TBMs not destroyed within 400 seconds of being detected by ATIS.</td>
<td>&lt;=2</td>
</tr>
</tbody>
</table>
Results

- 3 interceptors can handle the 10 threats (with a max of four leakers) if they arrive at a rate slower than 1 in 25 seconds
- 4 interceptors can handle the 10 threats (with a max of two leakers) if they arrive at a rate slower than 1 in 25 seconds
- 5 interceptors can handle the 10 threat with no leakers

<table>
<thead>
<tr>
<th>Number of Interceptors</th>
<th>TBM Inter-arrival</th>
<th>Average Response Time</th>
<th>Number of Leakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
<td>347.1</td>
<td>4</td>
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<tr>
<td></td>
<td>25</td>
<td>270.1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>180.6</td>
<td>0</td>
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<tr>
<td></td>
<td>75</td>
<td>159</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>159</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>283.9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>212.9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>50</td>
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<tr>
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<tr>
<td>5</td>
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<td>245.5</td>
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<tr>
<td></td>
<td>100</td>
<td>159</td>
<td>0</td>
</tr>
</tbody>
</table>

MOE = 93%
Conclusion & Future Work

• A formal dynamic model of federated SOAs suitable for analysis and evaluation
  – Dynamically federate with NCE systems through COI registries and by utilizing the NCES to share enterprise-level information
• An approach for constructing an event driven SOA compliant to DoDAF v1.5
• Behavioral and Logical evaluation of business service and processes, and baseline performance measures of SOA using Colored Petri Nets

• Future work
  – Extend the analysis and evaluation to capture SOA infrastructure
QUESTIONS?