Model-Driven UAS ISR Tradespace Analysis

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www.sercuarc.org
• Introduction and Overview
• Case Study: TBM Identification and Elimination: 3-Tier UAS SoS
• System Cost Modeling and SysML Integration
• Conclusions and Future Work
• Joint approach to incorporate methods in case studies for assessing impacts of requirements changes and scenario variations in MBSE tools, Modeling and Simulation (M&S) environments.

• Focus on translations between models/tools in MBSE, specifically mapping architectural elements into behavior/performance analysis and cost model inputs.
  — SysML, DoDAF, Monterey Phoenix, parametric cost models, M&S environments

• Initial application to UAV Intelligence, Surveillance and Reconnaissance (UAS ISR) mission involving heterogeneous teams of autonomous and cooperative agents.

• AFIT develop mission CONOPS, Architectures and provide modeling support.

• NPS provide cost modeling expertise, tools and modeling support.

• Approach
  — Develop operational and system architectures to capture sets of military scenarios.
  — Develop the architectures in MBSE environments.
  — Design and demonstrate UAS ISR tradespace in MBSE and/or M&S environments.
  — Develop cost model interfaces for components of the architectures in order to evaluate cost effectiveness in an uncertain future environment.
• Goal of Total Ownership Cost (TOC) modeling to enable affordability tradeoffs with otherilities
  — Integrated costing of systems, software, hardware and human factors across full lifecycle operations
  — Combine with other MBSE architecture-based behavior and performance analysis

• Current shortfalls forilities tradespace analysis
  — Models/tools are incomplete wrt/ TOC phases, activities, disciplines, SoS aspects
  — No integration with physical design space analysis tools or system modeling

• Cost estimation can be improved by using the same architectural definitions for cost model inputs, without the need for independent cost modeling expertise and effort expenditure.

• Developing translation rules and constructs between MBSE methods, performance analysis and cost model inputs.

• Demonstrating tool interoperability and tailorability
UAS Mission Summaries

- Single UAS Search and Target Tracking (Simple Mission)
- UAS Pair Search and Target Tracking
- Find, Fix and Finish Terrorist Leadership (1)
- Find, Fix and Finish Terrorist Leadership (2)
- Mobile Missile Launcher Monitoring (1)
- Mobile Missile Launcher Monitoring (2)
Single UAS Simple Mission Threads

- Launch
- Navigation and flight
- Search and target ID including evaluation
  - Probabilistic target detection allowing for false targets and missed detections
- Target tracking
- Return/recovery

"Enumeration of these in MBSE models constitutes primary size input for Constructive Systems Engineering Cost Model (COSYSMO)"
UAS Mission
Nominal Cost Comparisons

Relative System Size/Cost

# Mission Threads

Mission Baselines

Single UAV (Simple)  UAV Pair  Find, Fix and Finish Terrorist Leadership (1)  Find, Fix and Finish Terrorist Leadership (2)  Mobile Missile Launcher Monitoring (1)  Mobile Missile Launcher Monitoring (2)
Case Study Method

• Use various MBSE methods and tools to evaluate behavior and performance analysis in the face of requirements changes and System of System (SoS) architectural variations.

• Develop operational and system architectures to capture sets of UAS military scenarios for cooperative swarms with 3 UAS group sizes

• Develop the architectures in MBSE environments.
  — SysML diagrams and executable activity models using Innoslate

• Develop cost model interfaces for components of the architectures in order to evaluate cost effectiveness in an uncertain future environment.
  — XML model files parsed automatically to extract cost model inputs

• Design and demonstrate UAS ISR tradespace including cost in integrated MBSE environment with executable models of architectures
• Introduction and Overview
• Case Study: TBM Identification and Elimination 3-Tier UAS SoS
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• Conclusions and Future Work
Implementation of Methodology

Operational Need

1. Increase in Theater Ballistic Missile (TBM) threats.
2. TBM launchers employing shoot-and-scoot technique, increasing challenge to counter-TBM operations.
3. Capability to preemptively seek and destroy TBM launchers.

CONOPS overview

1. Multi-tier UAS System-of-Systems to
   i. Maintain persistent situational awareness over a designated area
   ii. Search and locate possible TBM Launchers
   iii. Target and strike the located launchers.
   iv. Perform BDA?

2. Leverage on capabilities of different groups of UAS and sensor systems.

3. Optimizing UAS employment for mission effectiveness while minimizing operational cost and risk

4. Cooperative control among various UAS groups to assign roles and plan safe routes for ingress and egress.
Measures of Performance

1. Target Acquisition Pct

\[ Target \, Acquisition \, (Percentage) = \frac{Target \, Positively \, Acquired}{Total \, number \, of \, Targets \, encountered} \times 100\% \]

2. False Alarm Pct

\[ False \, Alarm \, (Percentage) = \frac{False \, Target \, Acquired}{Total \, number \, of \, targets \, declared \, in \, area} \times 100\% \]

3. Time-to-Strike

\[ Time \, to \, strike = Bomb \, launched \, Time - Target \, Acquisition \, Time \]

4. Target Destruction Pct

\[ Target \, Destruction \, (Percentage) = \frac{Target \, Destroyed}{Total \, number \, of \, Targets \, encountered} \times 100\% \]
Implementation of Methodology

High Level DoDADF Architectural Products

1. AV-1 : Overview and Summary Information
2. OV-1 : High-level Operational Concept Graphic
3. OV-2 : Operational Resource Flow Description
4. OV-5a : Operational Activity Decomposition Tree
5. OV-5b : Operational Activity Model
6. OV-6a : Operational Rules Model
7. DIV-2 : Logical Data Model
Implementation of Methodology

OV 1: High-level Operational Concept Graphic

Multi-Tiered UAS System
Mission Parameters -> ISR Task -> Track & Target -> Strike Threat -> BDA -> Egress

- Find TBM Site
- Dynamic Targeting and Strike
- Battle Damage Assessment
- Tracking and Target Confirmation
- Networked, Autonomous, Cooperative, Multi-Tiered UAS System of Systems for TBM Site Identification and Elimination

AO
Command Post
(Mission Commander)
OV 5a: Operational Activity Decomposition Tree

Decomposed into 4 levels to provide level of depth required for effective development of EA.
Implementation of Methodology

OV 5b: Operational Activity Model

5 Swim-lanes
- ISR UAS
- Surveil UAS
- Strike UAS
- BDA UAS
- Decision Makers
**Implementation of Methodology**

**OV 6a: Operational Rules Model**

<table>
<thead>
<tr>
<th>Operational Activity</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive Flight Plan (ISR)</td>
<td>Activate by Decision Makers through the Assign ISR UAS activity. Signify the activation of the Multi-tiered UAS SoS.</td>
</tr>
<tr>
<td>Assign Surveil UAS</td>
<td>Activated by Decision Makers if TBM Located = TRUE.</td>
</tr>
</tbody>
</table>
| Receive Flight Plan (Surveil, Strike or BDA) | Activated when Assign Surveil/Strike/BDA UAS = TRUE  
The time delay is dependent on Type of C2 and associated distribution.                                                                                                                                    |
| Ingress into AOR                          | Activated after UAS Receive Flight Plan. The duration required for Ingress into AOR is dependent on Type of C2 and associated distribution.                                                             |
| TBM Located?                              | IF TBM located, activate Locate TBM (ISR) activity which updates Decision Makers, THEN Decision makers assign appropriate Surveil UAS through Assign Surveil UAS activity, ELSE continue TBM Located? Task UNTIL search is completed.  
The probability of TBM located is dependent on the Type of Sensors.                       |
| TBM Confirmed?                            | IF TBM confirmed, activate Confirm TBM confirmation activity which updates Decision Makers, THEN Decision makers assigned appropriate Strike UAS through Assign Strike UAS activity, ELSE continue TBM Confirmed? Task UNTIL search is completed.  
The probability of TBM Confirmation is dependent on the Type of Sensors.                     |
| Target Lock-on?                           | IF TBM lockon, activate Lock-on Target (Strike) activity that updates Decision Makers, THEN Decision makers activate Send Strike Confirmation activity and Strike UAS executes Launch Missile (Strike) Activity. The Decision makers are updated and activate Assign BDA UAS activity. |
| TBM Destruction Confirmed?               | IF TBM destruction confirmed, the scenario ends, ELSE Decision makers assigned second Strike UAS if scenario dictates.  
The probability of TBM Destruction Confirmation is dependent on the probability of destruction of the Strike UAS.                                             |
# Implementation of Methodology

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Variants</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision-Capability</td>
<td>Manual C2</td>
<td>1. Speed of decision making</td>
</tr>
<tr>
<td></td>
<td>Autonomous C2</td>
<td>2. Quality of decision making</td>
</tr>
<tr>
<td>Sensor Capability</td>
<td>Normal Sensor</td>
<td>1. Target acquisition</td>
</tr>
<tr>
<td></td>
<td>High End Sensor</td>
<td>2. False Alarm</td>
</tr>
<tr>
<td>Number of Strike UAS deployment</td>
<td>1 x Strike UAS</td>
<td>1. Time-to-strike</td>
</tr>
<tr>
<td></td>
<td>2 x Strike UAS</td>
<td>2. Target destruction</td>
</tr>
</tbody>
</table>
# Implementation of Methodology

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Effects</th>
<th>Affected Activity Nodes</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decision-Capability</strong></td>
<td>Speed of decision making</td>
<td>Receive Target Area (Surveil)</td>
<td>Time Delay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Receive Target Coordinates (Strike)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Receive Strike Area (BDA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality of decision making</td>
<td>Ingress into AOR (Surveil)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ingress into AOR (Strike)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ingress into AOR (BDA)</td>
<td></td>
</tr>
<tr>
<td><strong>Sensor Capability</strong></td>
<td>1. Target acquisition</td>
<td>Locate TBM (ISR)</td>
<td>• Probability of Positive Detection</td>
</tr>
<tr>
<td></td>
<td>2. False Alarm</td>
<td>Confirm TBM Location (Surveil)</td>
<td>• Probability of False Detection</td>
</tr>
<tr>
<td><strong>Number of Strike UAS deployment</strong></td>
<td>Target destruction</td>
<td>TBM Destroyed</td>
<td>Probability of Destruction</td>
</tr>
</tbody>
</table>
Threat Assessment shows possible TBM deployment within Area of Operations (AO) During each run, 2 x Targets and 2 x False targets randomly deployed over the 40 grids

**Simulation Scenario**

- 1 x ISR UAS deployed to conduct ISR [marked by \(...\)]. Follow anti-clockwise search pattern over AO.
- When potential target are located, small UAS are deployed to Confirm and track target. Simulation limited to 2 x Surveil UAS [marked by \(...\)].
- Strike UAS deploy to strike target, once target confirmed [marked by \(...\)].
- Small UAS to conduct BDA [marked by \(...\)].

Total of 50 runs carried out per cycle, generating 100 targets and 100 false targets. Total of 50 cycles executed as part of Monte Carlo simulation for each scenario.

**Total of 8 Simulation Scenarios**

<table>
<thead>
<tr>
<th></th>
<th>Centralized Manual C2</th>
<th>Autonomous C2 Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal ISR Sensor</td>
<td>1 x Strike UAS</td>
<td>1 x Strike UAS</td>
</tr>
<tr>
<td></td>
<td>2 x Strike UAS</td>
<td>2 x Strike UAS</td>
</tr>
<tr>
<td>High End ISR Sensor</td>
<td>1 x Strike UAS</td>
<td>1 x Strike UAS</td>
</tr>
<tr>
<td></td>
<td>2 x Strike UAS</td>
<td>2 x Strike UAS</td>
</tr>
</tbody>
</table>
MOP 4: Target Destruction Percentage

Summary of Target Destruction Percentage Data

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Type of C2</th>
<th>Type of Sensor</th>
<th>No. of Strike UAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manual</td>
<td>Normal</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Auto</td>
<td>Normal</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Manual</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Auto</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Manual</td>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Auto</td>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Manual</td>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Auto</td>
<td>High</td>
<td>1</td>
</tr>
</tbody>
</table>
MOP 4: Target Destruction Percentage

\[ \text{Target Destruction (Percentage)} = \frac{\text{Target Destroyed}}{\text{Total number of Targets encountered}} \times 100\% \]

- Simulation confirmed significant impact in difference in Design Parameters:
  - Type of Sensors
  - Number of Strike UAS

- Need to maintain High Resolution Sensors to meet Threshold value.

- Need to maintain both High Resolution Sensors and 2 x Strike UAS to meet Objective values
## Summary of Results

<table>
<thead>
<tr>
<th>MOP</th>
<th>Design Parameters</th>
<th>Simulation Results</th>
<th>Pct Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Acquisition Percentage</td>
<td>Type of Sensor</td>
<td>High: 85.5%</td>
<td>61.5% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal: 52.9%</td>
<td>over Normal Sensor</td>
</tr>
<tr>
<td>False Alarm Percentage</td>
<td>Type of Sensor</td>
<td>High: 0.4%</td>
<td>95.6% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal: 9.6%</td>
<td>over Normal Sensor</td>
</tr>
<tr>
<td>Time-to-Strike</td>
<td>Type of C2</td>
<td>Autonomous: 91.2 mins</td>
<td>9.8% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manual: 100.1 min</td>
<td>over Manual C2</td>
</tr>
<tr>
<td></td>
<td>Number of Strike UAS</td>
<td>1 x Strike UAS: 94.6 min</td>
<td>2.1% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 x Strike UAS: 96.9 min</td>
<td>over 2 x Strike UAS</td>
</tr>
<tr>
<td>Target Destruction Percentage</td>
<td>Type of Sensors</td>
<td>High: 75.1%</td>
<td>62.2% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal: 46.3%</td>
<td>over Normal Sensor</td>
</tr>
<tr>
<td></td>
<td>Number of Strike UAS</td>
<td>1 x Strike UAS: 54.8%</td>
<td>21.7% improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 x Strike UAS:</td>
<td>over 2 x Strike UAS</td>
</tr>
</tbody>
</table>
Agenda

• Introduction and Overview
• Case Study: TBM Identification and Elimination 3-Tier UAS SoS
• System Cost Modeling and SysML Integration
• Conclusions and Future Work
## COSYSMO Size Inputs

<table>
<thead>
<tr>
<th>Size Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements</td>
<td>The number of requirements for the system-of-interest at a specific level of design. Requirements may be functional, performance, feature, or service-oriented.</td>
</tr>
<tr>
<td>Interfaces</td>
<td>The number of shared physical and logical boundaries between system components or functions (internal interfaces) and those external to the system (external interfaces).</td>
</tr>
<tr>
<td>Algorithms</td>
<td>The number of newly defined or significantly altered functions that require unique mathematical algorithms to be derived in order to achieve the system performance requirements.</td>
</tr>
<tr>
<td>Operational Scenarios (Threads)</td>
<td>Operational scenario threads that a system must satisfy, including nominal and off-nominal threads.</td>
</tr>
</tbody>
</table>
SySML to COSYSMO Mapping

SysML

- Package Diagram
- Requirements Diagram
- Internal Block Diagram
- Block Definition Diagram
- Parametric Diagram
- Block Definition Diagram
- Use Case Diagram

COSYSMO

- System Size

# Requirements
# Interfaces
# Algorithms
# Operational Scenarios (Threads)
TBM 3-Tier UAS Scenarios (Use Cases with Threads)
TBM 3-Tier UAS Example Requirements

<< Requirement >>
UAS Group 1
- Perform Track and Target Operations

<< Requirement >>
Find Target
- The UAS shall find a target.

<< Requirement >>
Fix Location
- The UAS shall fix the target's location.

<< Requirement >>
Track Moving Target - EO
- The UAS shall track a moving ground target with EO.

<< Requirement >>
Track Moving Target - IR
- The UAS shall track a moving ground target with IR.

<< Requirement >>
Mission Start
- The Ground Station shall send start mission parameters to UAS.

<< Requirement >>
Ground Station Operations

<< Requirement >>
Receive Imagery
- The Ground Station shall receive imagery from the UAS.

<< Requirement >>
Save Images
- The Ground Station shall be able to save images for one full mission.

<< Requirement >>
Communications Group 1/2
- The Ground Station shall perform communications with the UAS Group 1/2.

<< Requirement >>
Communications Group 3/4
- The Ground Station shall perform communications with the UAS Group 3/4.

<< Requirement >>
C2
- The Ground Station shall send C2 messages to the UAS.

<< Requirement >>
Receive Status
- The Ground Station shall be able to receive status messages from the UAS.
TBM 3-Tier UAS Example Interfaces (Ports)

Weapon Payload
- Target Data
- Track Entity

Payload Data: C2Payload:C2
Payload Status:

UAS Navigation
- Entity Found
- Process Destination Command
- Process Entity Location
- Report Telemetry
- Track Entity Velocity

C2:C2Comms
Airframe Data: Airframe Data
Airframe Status: Airframe Status
Nav Data: Nav Data
Payload Data: Payload Data
Payload Status: Payload Status
XML Interface Processing

- `<entity id="e4RWJH">
  <name>Flight Activation</name>
  <description/>
  <hidden>false</hidden>
  <locked>false</locked>
  <schemaClassId>C1</schemaClassId>
  <number/>
- `<doubleAttribute schemaPropertyId="P4">
  <doubleValue>0.0</doubleValue>
</doubleAttribute>
- `<durationAttribute schemaPropertyId="P2">
  <doubleValue>1.0</doubleValue>
  <units>HOURS</units>
</durationAttribute>
- `<labelId>L60</labelId`
- `<simulationData>`
  `<type>SERIAL</type>`
  - `<controlStructure id="57bdf94d-cb13-42e5-9e5b-72df52a9fc1">
      `<type>START</type>`
      - `<successorStructure id="fe49a8a-d37b-44d1-9ff3-614416d611e">
        `<type>END</type>`
    </successorStructure>
  </controlStructure>`
</simulationData>`
Example COSYSMO Estimate

SysML COSYSMO

System Size

<table>
<thead>
<tr>
<th>Input Method</th>
<th>File Input</th>
<th>Select Input File</th>
<th>distiller.xml</th>
</tr>
</thead>
</table>

# of System Requirements | Easy | Nominal | Difficult |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

# of System Interfaces

# of Algorithms

# of Operational Scenarios

System Cost Drivers

- Requirements Understanding: Nominal
- Architecture Understanding: Nominal
- Level of Service Requirements: Nominal
- Migration Complexity: Nominal
- Technology Risk: Nominal

Maintenance: Off

System Labor Rates

Cost per Person-Month (Dollars): 10000

Calculate

Results

Systems Engineering

Effort: 25.6 Person-months
Schedule: 4.4 Months
Cost: $255525

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• Introduction and Overview
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Ongoing Results

• 2016
  — Increasing complexities of Multi-Tier UAS missions
  — Baseline case study: TBM 3-Tier UAS SoS
  — Alternative approaches to CONOPS modeled – evaluated against MOEs/MOPs
  — Demonstrated cost model interfaces for SysML and Monterey Phoenix

• 2015
  — Demonstrated architectural tradespace with simpler UAV swarm models for further elaboration in next phase
    o Base models of simple UAV scenarios developed with Innoslate and Monterey Phoenix
  — Innoslate model used to evaluate behavior and performance of architectural variations
  — Initial assessment of Monterey Phoenix (MP) for automatically providing cost information from architectural models.
  — Cost models were integrated in different ways with MBSE architectural modeling approaches and as web services for tool interoperability.
**Systems Engineering Cost Model**

**Sizing Correlation in MBSE Tools**

- **Requirements**
  The number of requirements for the system-of-interest at a specific level of design.

- **Interfaces**
  The number of shared physical and logical boundaries between system components or functions (internal interfaces) and those external to the system (external interfaces).

- **Algorithms**
  The number of newly defined or significantly altered functions that require unique mathematical algorithms to be derived in order to achieve the system performance requirements.

- **Operational Scenarios**
  Operational scenarios that a system must satisfy, including nominal and off-nominal threads.

- These size drivers are further weighted for complexity levels.
Conclusions and Future Work

- We have found a strong correspondence between SysML constructs and system size measures of requirements, interfaces, algorithms, and operational scenarios.
  - Still comparing approaches for complex algorithm representations in SysML
  - Require additional attributes for modeling complexity levels of size drivers

- Continue transcribing all UAS architectural variations into SysML for cost tradeoffs to evaluate with other Measures of Effectiveness
  - Expanded mission sets to include heterogeneous UAS teams and more complex scenarios

- Apply method and case study with other MBSE tools, evaluate and compare
  - More detailed modeling to support thread, requirements, functions, algorithms and interface definition

- Develop guidelines with examples for practitioners on modeling decomposition levels of detail

- Collaborate with RT-166 providing shared UAS CONOPS and related SysML artifacts
Completed Student Theses


References


Monterey Phoenix Overview

- Monterey Phoenix (MP) is an approach to formal software and system specification based on behavior models.

- A view on the architecture model as a high-level description of possible behaviors of subsystems and interactions between subsystems.

- The emphasis on specifying the interaction between the system and its environment.

- The behavior composition operations support architecture reuse and refinement toward design and implementation models.

- Executable architecture models provide for system architecture testing and verification with tools.

- See [http://wiki.nps.edu/display/MP](http://wiki.nps.edu/display/MP)