Development, Validation and Implementation Considerations of a Decision Support System for Unmanned & Autonomous System of Systems Test & Evaluation

Test Week 2010

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Desired Transition Partners
The Challenge:
Science Fiction to Reality

“You will be trying to apply international law written for the Second World War to Star Trek technology.”

Scoping the Challenge

2008 Defense Science Board in Regards to Systems of Systems

• Findings
  – Acquisitions process generally tailored to the development of individual systems, not systems of systems (SoS)
  – Some mission critical testing of SoS capability areas often accomplished for the first time in OT or when deployed
  – Testing all the SoS requirements of all the systems is impossible
  – SoS requires better approaches to requirements definition, resources, and acquisition processes, including judicious T&E

• Recommendations
  – Formulate alternative strategies to adapt current requirements, acquisition and funding processes to enable timely, efficient, and effective T&E of SoS capabilities

Scoping the Challenge

**FY2009-2034 Unmanned Systems Integrated Roadmap**

- Unmanned Systems Investment Areas
  - Reconnaissance and Surveillance
  - Target Identification and Designation
  - Counter-Mine and Explosive Ordinance Disposal
  - Chemical, Biological, Radiological, Nuclear (CBRN) Reconnaissance

- Unmanned Systems T&E Goal
  - Ensure test capabilities support the fielding of unmanned systems that are effective, suitable and survivable

Scoping the Challenge

**USD(DOT&E) T&E Initiatives Memo – Nov 2009**

- New Initiatives for future testing
  - Field new capability rapidly
  - Engage early to improve requirements
  - Integrate developmental, live fire, and operational testing
  - Substantially improve suitability before Initial Operational Test & Evaluation (IOT&E)

Office USD(DOT&E), Memorandum on Test and Evaluation (T&E) Initiatives, Nov 2009
Scoping the Challenge

**UASoS T&E Need**
- Accelerate test planning by supporting automation of current human-intensive (potentially error-prone) test planning process
- Optimize the joint mission oriented strategy by addressing and balancing multiple criteria
- Predict, detect, and adapt to undesirable emergent behavior

**S&T Challenge**
- Perform R&D of a multi-dimensional framework for knowledge representation across UASoS
- Perform R&D to develop analyses / simulations across UASoS models
- Develop Decision Support System (DSS) prototype improving test planning
Meeting the Challenge

• Unmanned and autonomous system of systems (UASoS) is on the horizon for DoD capabilities

• Current Test and Evaluation (T&E) structure needs to be set up to effectively handle UASoS

• TRMC awarded 3 year T&E/S&T contract to MIT, USC & UT Arlington to develop UASoS prototype T&E tool

• Prototype will enable strategic planning and prioritization of UASoS testing (risk, cost, schedule and resources)

• Prescriptive Adaptive Test Framework Decision Support System (DSS)
PATFrame’s Objective

• Research and develop a technology to provide a decision support system encompassing a prescriptive and adaptive framework for UASoS Testing (Air, Land, Sea and Space)
  – The PATFrame prototype will use a software dashboard that will enable improved decision making for the UAS T&E community
  – Addresses UAST focus areas of Prescribed System of Systems Environments and Adaptive Architectural Frameworks
  – Draws from experts in the following fields
    • Systems of systems
    • Test & evaluation
    • Decision theory
    • Systems engineering
    • Software architectures
    • Robotics and modeling
**Example Scenario #1 – (GH, Predator and MIUGS Sensor Testing)**
- Motion sensors sense motion of the target convoy (CUE)
- Global Hawk UAV utilizes GMTI capability follow the convoy
- Predator UAV with EO capabilities can confirm target SCUD launcher
- Performs the CUE, FIND, FIX, TRACK, TARGET functions of kill-chain

**KPP’s (For System Under Test – not PATFrame)**
- Track missile launcher target vehicle for the maximum amount of time possible
- Identify target vehicle amongst other vehicles with XX% confidence
- Geospatial accuracy of the vehicle within +/- 1 ft
- Quality of communications equipment

**Example Scenario #2 – (Futuristic UASoS Testing)**

- UAVs acting as SoS with near full autonomy tracking target vehicle in convoy
- Ground motion sensors cue the airborne UAVs in order to start the surveillance routine of (FIND, FIX, TRACK, TARGET)
- UAV SoS captures / synthesizes / relays information to geographically separated intelligence cell

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What Use Cases Provide

• Provide insight into various test applications (threads) for PATFrame that influence design

• Representative use cases being investigated
  – Anticipate undesired behaviors during testing of UASoS
  – Allows for test prioritization using: Real Options, DOE, Value Based Testing and Cost Based Testing
  – Predict effects of autonomous behavior on “ilities”

• PATFrame applicable to all levels of UASoS T&E
Characteristics & Capabilities of Decision Support Systems

- **Data access**: Standalone, integration and Web-based
- **Modeling and analysis**: Semi-structured and unstructured problems
- **Ease of development by end users**: Support managers at all levels
- **Humans control the process**: Support Individuals and groups
- **Effectiveness, not efficiency**: Interdependent or sequential decisions
- **Interactive ease of use**: Support intelligence, design, choice implementation
- **Adaptable and flexible**: Support variety of decision processes and styles

Project Description

**T&E Needs**
- Automate UASoS test planning
- Balance multiple criteria in UASoS mission-oriented T&E
- Predict, detect, adapt to undesirable emergent behavior

**S&T Solutions**

**UASoS Decision Support System (DSS) Solution Grouping**

- **UASoS Modeling**
  - Ontology
  - Architecture
  - Design idioms
  - Parametric models

- **UASoS Analysis & Simulation**
  - T&E Strategy Alternative Analysis
  - Real Options
  - QoS Analysis & Simulation
  - System Dynamics

**Major DSS Components (Technology)**

**DSS Prototype**
Value of PATFrame

• Addresses challenges associated with the T&E of complex autonomous UASoS

• Overcomes shortfalls of the “As-is” Test and Evaluation enterprise
  – Primarily man-in-the-loop and single system focused
  – SoS testing primarily not conducted until after development
  – Difficulty predicting cost, schedule and resources required

• PATFrame is at the intersection of *unmanned & autonomous* and systems of systems
  – Focuses on decision support with applicability to all levels of T&E
  – Understanding of dependencies / relationships of the UASoS
  – Supports safety, suitability, effectiveness and survivability of UASoS
Conclusion

• Unmanned autonomous systems of systems is on the horizon for future DoD capabilities

• DoD is investing in technologies to the allow successful T&E of UASoS

• PATFrame is researching and developing a decision support system envisioned to enable successful T&E planning
  – Cost, schedule and resource allocation

• Future work
  – Elaborate the system requirements for PATFrame
  – Refine the PATFrame system architecture
  – Validate & Verify PATFrame via scenarios (threads)
Questions / Comments

http://mit.edu/patframe
PATFrame DSS Schematic View
Use Case: Discover Unwanted Emergent Behavior

**Use Case Name:** Discover Unwanted Emergent Behavior

**Goal:** List the optimum set of test cases in order to discover unwanted emergent behaviors in a timely and cost-effective manner.

**Summary:**
- Tester characterizes each SoS component system
  - Maturity, size, bandwidth required, energy, autonomy, adaptability, risks to tester, cost to test, complexity, etc.
- Tester characterizes relationships *between* components in SoS
  - Dependencies, types of interactions, frequency of interactions, spatial, information flow, etc.
- Tester characterizes test cases
  - Mapping of test cases to component systems & capabilities
  - Cost, risk, safety
- PATFrame produces an ordered list of test cases, sorted by the probability of exposing an unwanted emergent behavior

**Stakeholders:** Tester, Test Management, Project Management

**Actors:** Tester
Use Case: Design of Experiments and Test Prioritization

- **Use Case Name:** Prioritize and Define a Battery of Tests for a SoS composed of autonomous UAVs and ground sensors

- **Goal:** Use Design of Experiments (DOE) to plan a set of tests specifically tailored to the unique aspects of an Autonomous System of Systems (emergence, learning behavior, interactions, etc.)

- **Summary:**
  - User inputs information about Systems Under Test, such as requirements, architecture, and UAS-Specific Traits (learning, etc.)
  - User inputs the types of tests available to assess system requirements.
  - User inputs desired confidence intervals and defines criteria for successful SUT performance.
  - User inputs constraints (budget, schedule, and availability).
  - PATFrame proposes a set of tests to perform, including a proposed schedule and the precise number and profile of trials.

- **Stakeholders:** DoD Test Personnel, PATFrame Team, UAST Evaluators, NST Evaluators, InterTec, TRMC

- **Actors:** User (Test Planners, Program Managers, and Schedulers)
Use Case: Predict Effects of Autonomous Behavior On QoS

- UAVs in the scenario include several autonomous behaviors
  - Tracking, following, route planning, network planning, etc.

- Behaviors impact the system QoS
  - Reliability, availability, durability, etc.
  - For example, network replanning increases connectivity but consumes more power

- PATFrame uses simulation to determine:
  - What QoS data should be gathered while testing different autonomous behaviors
  - What environmental conditions must be created to trigger different behaviors
Alignment of “As-Is” T&E Enterprise

**Strategic T & E Objectives**
- DoD 5000.2 Acquisition Cycle
- DoD Developmental Test Regs
- DoD Operational Test Regs
- Service T & E Regulations

**T & E Metrics**
- System Specification Requirements
- Measures of Effectiveness
- Measures of Suitability
- Safety

**Stakeholder Values**
- Verification of system requirements – Dev Tester
- Validation of system capabilities – Ops Tester
- Overall system performance in ops - User
- System performs as built - contractor
- Meets requirements w/in cost & schedule – PM

**Tactical T & E Objectives**
- DT verification of requirements
- OT validation of capabilities
- Emergent behaviors
- Subsystem interface linkages