Autonomous Systems Challenges to Test and Evaluation

Vincent P. Roske, Jr.
Ira Kohlberg
Raymond Wagner

This presentation is the work of the authors. The views, opinions, and findings should not be construed as representing the official position of the Department of Defense

National Defense Industrial Association
Test & Evaluation Conference
12-15 March 2012
Growing Demand for Autonomous Systems

- **DoD FY 2009-2034 Unmanned Systems Integrated Roadmap**
  - 311 Joint Capability Area (JCA) “Capability Targets”
  - 138 Systems
  - 41 Performance specifications
  - 17 technologies

- Uses: Weapons, C4ISR, logistics, transportation, medical care, decision support, and others related to development of unmanned autonomous systems
Current Themes in the Literature

• “There is a common misconception in the testing industry that all unmanned autonomous systems can be tested using methodologies developed to test manned systems”
  • The main difference lies in the unmanned autonomous system’s role in the decision process
  • “…there is a need for a methodology that completely tests this decision process without biasing the system into a default ‘‘human’’ solution.”
  • Won’t make decisions as humans do

• “Society holds robots to a higher standard and has a lower tolerance for their errors.”
  • Unmanned systems still fall short (from becoming autonomous) in three key areas: sensing, testing, and interoperability.”

Dr. Lora G. Weiss

Mike Thompson
“Testing the Intelligence of Unmanned Autonomous Systems”

Challenges: T&E of Autonomous Decision Making
• Test Program Design Methodology
• Ensuring Testability
  • Early Engagement in Requirements & System Design
  • Performance Metrics and Standards
  • Use of System Boundaries in the system design
What is Meant be “Autonomous”?  

• “Autonomous systems are...capable of performing tasks in the world by themselves, without explicit human control”
• “System that require no human intervention to perform any of its designed activities across all planned ranges of environmental conditions.”
• “Systems that sense, understand and act upon the environment in which they operate.”

The Distinction is in the Decision Making Algorithms

“Automated”
Make Prescribed Decisions
In predictable, understood conditions

“Autonomous”
Make Emergent & Adaptive Decisions
In unpredictable ways
In unpredictable conditions

• Definitions define “Automated” Systems
• Testing Elevators isn’t the Challenge
Decision Making Systems
A “Functions” Oriented Description

Three Core Functions:

- **Perception**: Observing (sensing) characteristics of the environment and forming an Understanding (orientation)
- **Decision Making**: Prescribing actions toward satisfying objectives
  - Mission Objectives (what to accomplish)
  - Behavioral Objectives (how, and how not, to accomplish)
- **Execution**: Implementing prescribed actions
A System Ontology
Forms, Functions and Decision Making Algorithms

Forms
- Cyber
- Platform

Functions
- Perception
- Decision Making (toward objectives)
- Execution

Decision Making Algorithms
- Automated
- Autonomous
  - Physical
    - Rule Based
    - Probabilistic
    - Electro/ Mechanical
  - Human
    - On Board
    - Remote
    - Software
- Land
- Air
- Sea
- Bio, Space
The Evolving “Share” of Autonomous Decision Making

Human Autonomous Algorithms: Current Role
- Make decisions that software cannot yet make
  - Being overcome by technology
- Enforce “human” standards on decisions made by non-human decision making
  - Limiting potential effectiveness
Autonomous Software Decision Making Algorithms

Human Autonomous Algorithms:
• Make decisions that software cannot yet make
• Enforce “human” standards on decisions made by non-human decision makers

Software Autonomous Algorithms:
• Make decisions in unpredictable ways
  • Adaptable decision making process (complex adaptive algorithms)
  • Evolve to “best” achieve objectives under constantly evolving conditions
  • Conditions and the “sequence” of conditions are unpredictable
    • Example: genetic algorithms in agent based simulations
• Require Metrics and Standards for:
  • The system to achieve objectives
  • The system to behave appropriately
T&E of Autonomous Systems
Characteristics, Metrics and Standards

**Characteristics, Metrics and Standards for:**
- **Observing:** Sensor design & performance
- **Orientating:** Situation understanding
- **Decision Making:** Solutions for achieving the objective conditions
  - **Conditions for Mission Objectives**
  - **Conditions for Appropriate behavior (toward others and self)**

**Challenges for System Designers (and T&E):**
- Establishing which **Characteristics** to observe
  - Environmental characteristics germane to the system’s objectives
  - Includes characteristics of objectives, of threats, of location, of neutrals, of the system itself, of many other germane entities
- Establishing **Metrics** for each characteristic
  - “What essentially describes (measures) the characteristics?
    - Tilt or height of a wall, GPS coordinates, motion of a human
- Establishing **Standards** for the Metrics
  - How “collapsed” (short or leaning) does a wall need to be to be “destroyed”:
    - To stimulate action (coordinates of “here” VS of the “destination”)
    - To know when to STOP or not take action
Autonomous System Testability

- Perception Function
- Decision Making Function
  - Decision making toward achieving objectives
- Execution Function

A T&E Question:
Q: Is an inadequate system performance toward its objectives due to:
  - Erroneous Perception of the environment? or
  - Erroneous Decision Making from a valid Perception of the environment? Or
  - The system’s inability to execute prescribed decisions?

Ensuring Testability Implies:
- A System Design discipline establishing “System Boundaries” between the Perception Function, the Decision Making Function and the Execution Function
- A Severability of T&E:
  - T&E of Perception from the T&E of Decision Making
    - Have “ground truth” for T&E of Perception, none for Decision Making
  - T&E of Decision Making from the T&E of Execution
    - Don’t have time to test Decision Making via Execution
1. **Perception Function** *(observe and orient)*

   - **T&E tasks:** Inform a confidence in the Perception Function by:
     - Stimulating sensors
     - Evaluating:
       - Sensor performance
       - Derived “orientations” / understanding
         - By comparison to “ground truth”

   - **T&E Challenges** *(Semi-Tough)*
     - Physics and facilities to adequately stimulate sensors (“Challenge” facilities)
       - Appropriately presenting characteristics for the sensors to measure
       - Including background interactions
Autonomous System T&E Challenges

2. Decision Making Function (prescribe actions toward objectives)

• **T&E Tasks:** Inform a confidence in the performance of autonomous decision making software
  - T&E of complex adaptive algorithms
    - Algorithms that constantly evolve their decision making process to produce “best solutions” based on an constantly evolving perception
    - Perception based on unpredictable and constantly evolving content and sequence of conditions.

• **T&E Challenges:** *(Tough)*
  - Informing a confidence in an algorithm’s decision making performance
  - **Testing algorithms across a vast scope of content and sequences of “conditions”**
    - Requiring new, advanced computer based test methods
  - **Developing a new, scientifically rigorous foundation for designing T&E programs**
    - Design of Experiments (DOE) on steroids
      - Effective T&E of unpredictable processes and emergent behaviors
  - **Collaboration early with designers to ensure decision algorithm testability**
    - Defining testable characteristics, metrics and establishing standards
    - Demands (professional/ moral/ legal) for ensuring adequate T&E to avoid unacceptable consequences from system behavior
    - Establishing Certifications for Autonomous System T&E methods and practitioners
  - T&E of Decision Making Algorithms in a system context
3. Execution Function (implements prescribed decisions)

- **T&E Tasks:** Inform a confidence in the system’s performance of prescribed actions
  - T&E of classic system functions
    - Animation, protection, power, reliability
    - Performance of system controls
      - Electro-hydraulic-mechanics
      - Autopilots, servos, etc

- **T&E Challenges:** *(Not so Much)*
  - Physical System Performance
    - Speed, Carrying Capacity, Energy Demand, Mobility, Fatigue, Vulnerability, etc
  - Traditional performance metrics
  - Traditional T&E methods
To ensure testability of unmanned autonomous system’s decision making performance in the system design:

- To provide system based characteristics, metrics and standards for use as conditions and standards for T&E of a system’s decision making performance.

To provide a scientifically rigorous basis for designing adequate T&E Programs:

- Define number and conditions of tests required to establish “confidence”.
- Comprised of an amalgam of:
  - Control Theory
    - For the system design to produce characteristics, metrics and standards for the decision making functions ... enabling testability.
  - Complexity Science
    - To address unpredictability, emergent behavior, fitness landscapes & attractors in the system design and in design of the T&E program.
  - Design of Experiments (DOE)
    - To prescribe the number and conditions of specific tests to be performed to support a confidence in the system’s behavior.
T&E of Autonomous Systems

Summary

• Traditional Systems T&E will not be Sufficient for T&E of Autonomous System.
  • Must now inform a confidence in “emergent”, rather than “prescribed”, performance
  • Resulting from adaptive decision making processes being driven by unpredictable conditions
  • Satisfying “mission accomplishment” as well as “acceptable behavioral” objectives

• To ensure Testability: (what to measure to establish performance)
  • Requires a new System Design discipline and an early collaboration with T&E
    • Establishing System Boundaries between Perception, Decision Making and Execution Functions
    • Incorporating decision algorithm performance in system control design
      • Producing Characteristics, Metrics and Standards for effective decision making

• To ensure adequate Testing (to inform confidence in the measured performance)
  • Requires a new, scientifically rigorous foundation for planning T&E programs for autonomous systems, Merging:
    • Control Theory
    • Complexity Science
    • Design of Experiments