Unmanned and Autonomous Systems of Systems Test and Evaluation: Challenges and Opportunities

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Abstract. The introduction of Unmanned and Autonomous Systems (UAS) brings substantial, interesting, and in many cases, new challenges to the Department of Defense's Test and Evaluation community. The test and evaluation of UASs becomes significantly more complicated than traditional systems, especially as we approach more fully autonomous systems and need to test integrated systems of systems in joint military operational testing environments. Compounding the multi-faceted considerations involved in test and evaluation, systems have continuously increasing complexity and capabilities and can be at different maturity levels. Emergent properties, particularly those that are unplanned and undesired, also need to be considered. Challenges identified by the Unmanned and Autonomous Systems Test community and related to the test and evaluation of the UASs are discussed. This paper presents various approaches for addressing these challenges including an innovative Prescriptive and Adaptive Testing Framework and decision support system, PATFrame.

Introduction

Background

The success of and subsequent demand for unmanned systems in Operations Enduring Freedom and Iraqi Freedom have driven the Department of Defense (DoD) to expand both its Research Development Test & Evaluation and Procurement efforts for unmanned systems. The DoD's budget for unmanned vehicles has grown 37.5% in the past two fiscal years alone from $3.9B to $5.4B (Keller 2009). In 2009, for the first time, the United States Air Force expected to purchase more unmanned aircraft than manned aircraft (Logan 2009). Not including the approximately 300,000 flight hours per year of the Army's Raven system, unmanned aerial vehicle flight hours across the DoD totaled nearly 165,000 in the 2006 fiscal year and grew by more than 50% to more than 258,000 in 2007 (Military.com 2009). Unmanned systems are overwhelmingly popular with commanders and soldiers alike. They have the capacity to provide new capabilities, such as persistent armed surveillance, and to keep troops out of harm's way by taking on especially dangerous jobs like defusing Improvised Explosive Devices (IEDs) and clearing minefields, and also allow operators to be removed from dull and dirty missions.

Traditional Test and Evaluation (T&E) has, necessarily, focused on manned systems. Traditional T&E programs do explore the interactions between the System Under Test (SUT) and its operational environment; however they do so at a very basic level by testing expected interactions between the SUT and other systems. Unmanned and autonomous systems represent a new engineering genus.

Motivation

The introduction of unmanned and autonomous systems and unmanned and autonomous systems of systems has brought significant and interesting challenges. These challenges are not only technological, but also include public perception and operational requirements. As we approach fully autonomous systems over a 30-year horizon, testing becomes enormously more difficult (Macias 2008), especially when considering the integration required with manned systems. An added complication results from the amalgamation of systems of systems (SoS), a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities (OUSD 2008). Additional complications include the trend for systems to have continuously increasing capability and the real possibility that systems within an SoS will be at different maturity levels. Emergent properties, both planned as well as potentially unplanned and undesired, also need to be considered.

The T&E phase of unmanned and autonomous systems and SoS has thus become an area of concern to ensure effective missions while maintaining safety during operation. However, current approaches for testing lack the ability to predict and adapt to current environments. In the complex systems community, alternative approaches to the design of testing can include solutions based on component technology, design patterns, and resource allocation techniques. We propose that an framework for the T&E of UASs can provide a key new contribution: the capability to predict when a test system needs to adapt. The proposed framework is a novel integration of control-theory-based adaptation, multi-criteria decision making and component-based engineering techniques. The goal is to augment traditional Department of Defense Architecture Framework (DoDAF) guidance towards capability-driven development with test architecture and test models specific to the UAS technology sector.

This paper presents an overview of the Unmanned and Autonomous Systems Test (UAST) community and identifies stakeholders within this group. Needs of the UAST community and challenges to T&E are discussed. Various approaches to address these challenges and opportunities are then defined. PATFrame, a proposed decision support system that incorporates a prescriptive and adaptive testing framework is discussed as a unique solution to some of the unmanned and autonomous SoS T&E challenges.

UAST Community and Stakeholders

The U.S DoD UAST community is made up of several important stakeholders. Two of the most influential are those who develop the UASs and those who test the systems. Development is managed by the program executive offices and program managers and executed through defense contractors.

UAST Steering Group

Within the military services, a special interest group has been formed to help address the challenges associated with testing UASs across the domains of space, air, land, sea and undersea. As the primary users of UASs, the branches of the military share common challenges in testing individual systems. Moreover, the need for joint operations, where multiple military services work together to achieve mission objectives, drives a need to integrate systems across traditional boundaries to ensure interoperability. For this purpose, the UAST steering group works to identify common issues and investments that can improve capabilities across the DoD. The UAST steering group consists of representatives from the Development Test Command (DTC), the Operational Test Command (OTC), the Air Force Operational Test and Evaluation Center (AFOTEC), and the Navy's Unmanned Combat Aerial System (N-UCAS). Figure 1 shows where the UAST Steering Group fits within the Test Resource Management Center (TRMC) hierarchy.

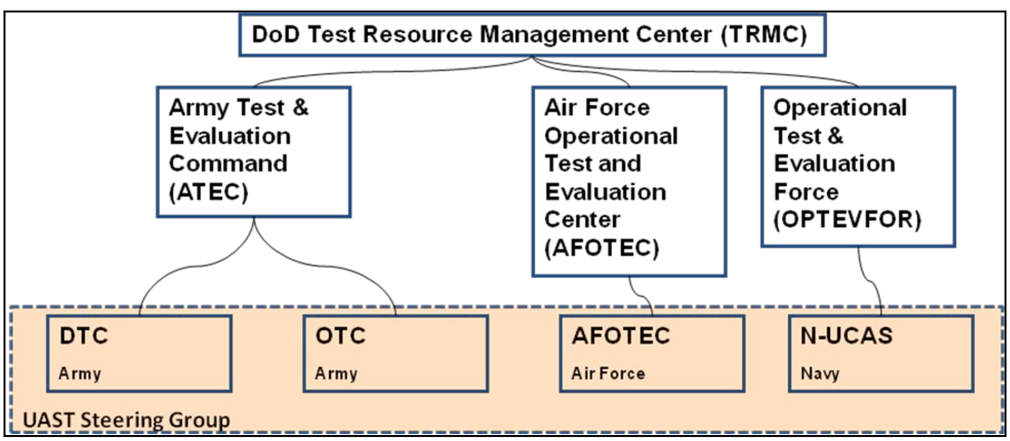

Figure 1. DoD TRMC and UAST Steering Group

The DoD TRMC provides investment funds for the advancement of test technologies that support joint operations in the UAS environment. Within this community, test organizations from each service provide support, facilities, and expertise to ensure that the technologies funded serve their needs. The Army Test & Evaluation Command (ATEC), Air Force Operational Test and Evaluation Center (AFOTEC) and the Navy Operational Test & Evaluation Force (OPTEVFOR) facilitate dialog in support of their programs of record (i.e., the Navy UCAS program) and overall T&E initiatives. The Army, like the other services, has more specific functions within the test community. These are represented by the DTC, which focuses on testing systems in the development stage, and the OTC, which focuses on use of the system in a realistic operational environment to gather data for assessment of the systems' effectiveness, suitability, and supportability in supporting a unit's mission.

Defense Contractors

Other important stakeholders in the UAST community include the prime contractors that develop the UASs for military and commercial use. Communication and cooperation with the contractors building the system is vital for success in any T&E effort for two reasons. First, the contractor must supply a testable system. Without adequate preparation in the requirements, design, and implementation phases, the contractor is often unable to provide a system which can be effectively tested. Second, the contractor has the best understanding of their system. It is always important to leverage contractor knowledge in the T&E process, but it is especially valuable in testing new or unique technology that the test community external to the contractor is unfamiliar with. When testers understand system architecture and modes of failure, they can better reduce risk through test. They are able to target the most important test points instead of treating the system as a "black box." In some cases, the contractors may not have enough visibility into the operational environment in which their system will be used. This is where a collaborative effort between the user and the developer can benefit the T&E process to ensure that the emergent properties of UASs in the SoS context can be adequately understood and tested.

UAS Test and Evaluation Challenges and Opportunities

This section discusses UAS T&E challenges. Gaps in the traditional T&E approaches and needs driven by changing requirements are presented. An overview of results from a meeting held with a UAST focus group is then discussed.

Gaps in Current "Traditional" T&E Approaches

The current T&E paradigm is over 40 years old, yet the DoD systems world has changed significantly and evolved to include UAS assets. The current engineering of these complex systems are driven by:

- "Systems of Systems and Complex Systems
- Extended enterprises and federated operations
- Network-centric paradigms
- Capability driven development
- Sustainability of systems
- Design for flexibility, adaptability, and composability
- Managing uncertainty in the environment and predictability of systems
- Spiral processes and evolutionary acquisition
- Model-based engineering" (OSD 2008)

In addition to development, these characteristics also drive the testing of UASs. Given the changes to the environment there are gaps between traditional approaches and contemporary needs for T&E. Given these gaps, new perspectives are necessary to address the follow critical challenges and opportunities:

- “Need to understand the impact of autonomy and cognition on T&E
- Need to test across five operational domains (space, undersea, sea surface, ground, and air)
- Need to accelerate UAST to match tempo of UAS deployment
- Need to provide T&E technologies in time to support developmental and operational tests and to verify performance before production/deployment
- Need for a T&E approach to address UAS already deployed in theater and tactical scenarios
- Need for new processes and methods for designing/executing tests of system of systems in the joint mission environment
- Need to capture how the operational environments for UASs dynamically change and evolve in future Warfighter mission
- Need to expand the community of interest through a federated approach toward common vision, values, and goals with common approaches to assess system performance as it pertains to capabilities supporting joint missions
- Need for a planning roadmap that identifies needs and gaps in current UAS T&E and serves as a useful tool for ensuring responsiveness to dynamic and complex Warfighter requirements including informing developers of when, where, and how technologies can be tested/inserted into systems and informing the acquisition community on types of testing required prior to accepting delivery.” (OSD 2008)

UAST Focus Group Workshop Overview

An Unmanned and Autonomous Systems Testing (UAST) focus group workshop was held August 10-12, 2009 at Fort Hood in Texas with the intent to build a community of interest to support development of the technology required to collaboratively analyze requirements of future, complex systems of systems involving unmanned and autonomous capabilities and determine the high value testing that reduces program manager risk for production of effective, sustainable, supportable, and safe systems. This objective directly ties to the UAS Roadmap goal to “ensure test capabilities support the fielding of unmanned systems that are effective, suitable, and survivable” (OUSD 2009). The workshop provided a forum to introduce stakeholders in the joint mission environment within the UAST community and to present their needs related to the T&E of unmanned and autonomous systems of systems. This forum was intended to identify T&E interest areas and challenges.

The focus group was hosted by the Operational Test Command (OTC) Transformation Technology Directorate (TTD), and was led by the Massachusetts Institute of Technology with support from the University of Southern California and the University of Texas at Arlington. U.S. Department of Defense (DoD) attendees included representatives from the Robotic Systems Joint Program Office, and systems development and test organizations within the Army, Navy, and Air Force. Each major stakeholder presented information about their organization.

UAST Challenges and Opportunities. One of the questions stakeholders were asked at the meeting was: “What are key challenges related to UAS T&E?” The stakeholders provided their responses verbally in a roundtable fashion where each stakeholder talked in turn. The challenges across the stakeholders were grouped given common concerns from stakeholders. Each of the challenges was then discussed in more detail with the meeting representatives. This allowed the understanding of each of the challenges to be refined and clarified by the university researchers and validated by the stakeholders. The set of challenges identified by the stakeholders are shown in Table 1.

Table 1. UAS T&E Challenges

Challenges
Need to address multiple constraints (examples of constraints include budget, schedule requirements, test range availability, personnel training, airspace restrictions, communications & communications off conditions, unmanned test approaches, collision avoidance)
Lack of knowledge base for unmanned and autonomous testing (including approaches, methods, and lessons learned)
Need to replicate realistic operational environment (desire the best feedback possible but field conditions can be difficult to replicate)
Need to deal with problems in real-time (System failures, equipment failures - need contingency plans)
Addressing the potential for unintended consequences (undesirable emergent behavior)
Ability to identify essential data required from test (sometimes evaluators don't know what they want and ask for everything)
Data overload (The ability exists to collect a lot of data. How can large amounts of data be properly evaluated?)
Ensuring strategic focus for testing and the early involvement of test personnel (There is an interest in taking a proactive vs. reactive perspective. Strategic involvement in capabilities development is desired.)
Safety issues & safeguards
Inexperienced testers (in domain and/or test process)
Staying involved after test (Interest in follow-through to determine causality)
Risk assessment
Inability to understand all the impacts and multiple levels of effects (e.g. cultural concerns, moral & ethical issues should be considered)
Configuration management of all relevant artifacts

An initial review of the challenges identified by the stakeholders includes issues that, at a minimum, relate to people, process, and technology. Additional work needs to be done to understand if the set of challenges identified by the focus group contain all the critical challenges to be addressed by the UAST community relative to UAS T&E and how these can be resolved. The challenges represent opportunities for researchers to contribute to the T&E domain.

UAST Ideas/Concerns Identification. Ideas and concerns related to UAST were gathered into a list during the stakeholder presentations and associated discussions. The topics were grouped into two categories: (1) general ideas/concerns for the UAST problem domain, and (2) specific areas to help bound PATFrame, a proposed solution to UAST concerns. Each DoD stakeholder was asked to evaluate each item in the compiled list and assess if they had a "high," "medium," or "low" interest in participating in future efforts related to the identified topic. A number was assigned to the high, medium, and low inputs. This allowed the calculation of a value across all stakeholders for the particular topic. Each instance of "high interest" was also noted in order to provide another metric for topic evaluation. The results, in the form of a matrix, are shown in Figure 2. The results provide an indication of stakeholder priority for the ideas and concerns identified at the meeting.

Approaches to Address UAST Challenges

While more detailed analysis needs to be performed to determine how to effectively deal with each of the identified challenges, there are current activities underway to address some of the challenges. Opportunities exist to address some of them utilizing proven methods and techniques from other disciplines. In order to increase the knowledge base and better understand the applicability of innovative ideas, it will also be extremely important to dialog with domain experts in the T&E and UAST community. The sections below discuss the current investment focus in

UAST, potential applicability of methods from other disciplines, and the need to dialog with experts in the UAST and T&E community, including a discussion of existing groups.

H - High interest (3) M - Medium interest (2) L - Low interest (1)	Participant A	Participant B	Participant C	Participant D	Participant E	Participant F	Participant G	Participant H	Participant I	Participant J	Participant K	Participant L	Participant M	# of Participants w/ High Interest	Totals
General Ideas/Concerns for the UAST problem domain															
Buildin a top-level ops model for UAST	H	H	-	M	H	H	M	H	L	H	H	L	L	7	28
Interactions of test technologies with each other, emergent behaviors	H	H	-	M	H	L	M	L	L	H	M	M	M	4	25
Organizational relationships among stakeholders (DoD, academic)	M	M	-	L	M	M	M	M	M	H	L	H	M	2	24
Challenge around the pace of UAS and UAST	M	H	-	H	H	M	M	L	L	M	H	L	L	4	24
Early on testing to guide development (can tools for testing also benefit)	H	H	M	H	M	H	M	L	L	H	L	M	M	5	28
Role of rapid acquisition, developmental testing, etc.	H	H	M	H	H	M	M	M	L	M	M	H	H	6	31
Specific Questions to help bound PATFrame															
Joint Test Scenarios	L	M	-	H	M	H	H	M	H	H	H	H	H	8	31
How to pick a joint program thread (use case) and get to the beef	H	H	-	L	H	H	H	H	H	H	M	L	L	8	29
Test views in DoDAF	H	M	-	H	M	H	M	M	H	M	L	L	L	4	25
Role of models/tools in T&E planning	H	M	-	H	M	H	M	H	M	H	H	M	M	6	30
PATFrame fidelity with respect to															
System quality	L	L	H	L	H	M	M	H	L	M	L	M	M	3	24
-ilities	L	H	H	L	H	H	M	H	L	H	L	M	M	6	28
Risk	L	H	M	L	H	H	M	H	M	M	H	M	H	6	30
PATFrame interface to other tools (existing & future)	H	-	-	M	H	M	M	H	H	H	M	M	M	5	27
Safety, Survivability, Suitability, Sufficiency	-	-	-	-	-	-	-	-	-	H	H	-	-	2*	6*

Figure 2. PATFrame Stakeholder Survey Results

DoD Investment Focus to Address Gaps and Challenges

The UAST focus area is a recognized part of the DoD Test Resource Management Center (TRMC) Test and Evaluation/Science and Technology Program. The UAST focus area allows the Government to identify and address current and future gaps or shortfalls by making science and technology investments in advanced technology development (OSD 2008). Investment focus areas include UAST modeling and architecture, UAST aspects and protocols, testbeds and test environments, and UAS Analytics. The following sections discuss some of the funded projects.

Roadmap Development and Technology Insertion Plan. The Roadmap Development and Technology Insertion Plan (RD-TIP) project is expected to produce a roadmap which is designed to improve the testing and evaluation of unmanned and autonomous systems. The unmanned and autonomous systems testing roadmap effort is planned to provide a vision to enable the T&E of evolving UASs (TRMC 2009).

OASIS-EIS. The Operational Test Command (OTC) Advanced Simulation and Instrumentation Suite (OASIS) Enterprise Integration Systems (EIS) is the program of record to adapt, buy, or create the common components for a family of integrated interoperable enterprise tools to support test technology "centers of gravity" (PEO STRI 2009). OASIS-EIS integrates test technologies and connects them into the live test environment. It provides a family of integrated systems that support operational testing. The supported centers of gravity include: (1) Live-Virtual-Constructive simulations, (2) data collection/reduction/analysis systems, (3) tactical systems, and (4) test control systems, networks, and infrastructure (U.S. Army Operational Test Command 2009).

PATFrame. Valerdi et al. (2007) offer a framework for examining the differences between systems engineering and system of systems engineering (SoSE) and which considers normative, descriptive, and prescriptive views. A prescriptive and adaptive framework for UAS Systems of

Systems (SoS) testing is proposed to address critical needs and challenges facing the UAST community. The framework will be implemented in a decision support system called PATFrame (Prescriptive and Adaptive Testing Framework). The objectives of PATFrame include: (1) develop an understanding of the theoretically best SoS test strategies through a normative framework, (2) determine the best in class test strategies available across industry and government through a descriptive framework, (3) develop a prescriptive framework for improving decision making according to normative and descriptive standards, and (4) provide a decision support tool that will enable improved decision making for the UAS T&E community. The effort includes the development of an adaptive architectural framework for SoS testing and it is proposed that this framework can provide a key and unique contribution: the capability to predict when a test system needs to adapt. The proposed framework is an innovative integration of control-theory-based adaptation, multi-criteria decision making and other techniques. The project is led by the Massachusetts Institute of Technology (MIT) with support from the University of Southern California (USC), the University of Texas at Arlington (UTA), and SoftStar Systems. Figure 3 shows where PATFrame fits within the UAST Projects Portfolio and its relationship to the test decision timeframe.

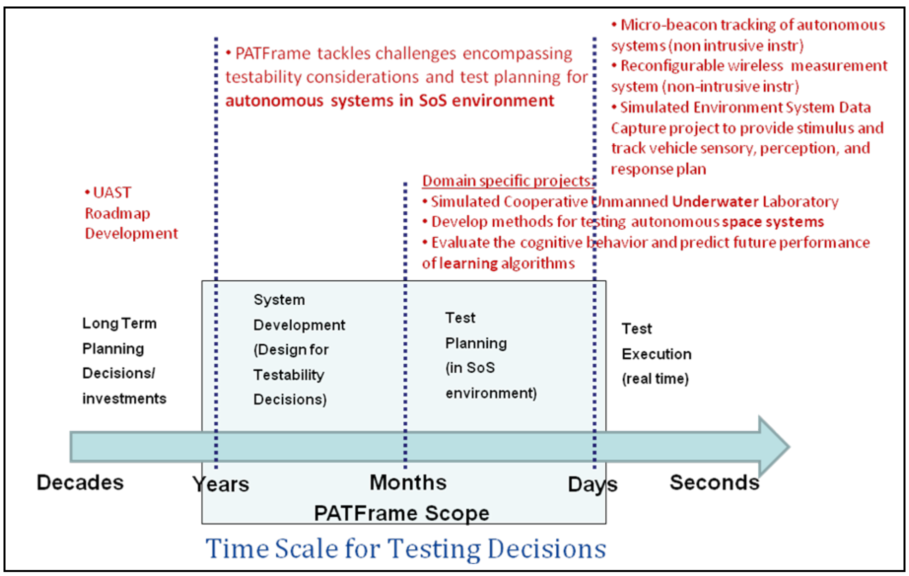

Figure 3. PATFrame Scope

Methods Utilized in Other Disciplines

There are many methods currently used in other domains and disciplines that may be used to advantage in the UAST domain. A few of these methods are discussed in the sections below and include ontologies, architectures, frameworks, simulation, decision support systems and real options.

Ontologies. An ontology can be expressed as concepts, relationships, and rules that govern the concepts within a domain (Benjamin 1995, Djuriæ et al 2005). Ontology models describe the objects and events in a domain, the relationships between objects and events, the use of objects and events both inside and outside the boundary of the domain, and rules that govern an entity's existence and behavior (Benjamin 1995). Ontologies have been developed in many domains. Systems engineering ontologies have been discussed in the literature and can provide common views of objects and events, relationships between objects and events, and rules in systems engineering to a multidisciplinary set of users and can be very helpful to the systems engineering community (Ferreira and Sarder 2008, Honour and Valerdi 2006, Madni 2006). The base of existing ontologies both in systems engineering and other areas can be leveraged to support the development of an ontology that addresses the unique aspects of the UAST community. A T&E focused ontology can provide a common language and basis of understanding and can be used to develop other products that all use the same foundation and semantics.

Frameworks. A framework is a conceptual structure that can be used to organize and understand complex concerns. Frameworks are used in many domains including systems engineering and for various purposes. There may be multiple frameworks applied to a domain that allow one to structure an area in various manners. For example, there are various architecture frameworks including DODAF, Ministry of Defense Architecture Framework (MODAF), Open Group Architecture Framework (TOGAF), and the Zachman Framework for enterprise architectures among others. Systems of systems UAST can benefit from the use of frameworks due to the complexity inherent in this area and the need to effectively evaluate various aspects and views so better visibility and alternative views of the challenges and potential solutions to the challenges can be defined and refined over time.

Architectures. There is considerable overlap between the various definitions of "architecture" and "framework." However, we believe that overlap to be unnecessary and actually distracting from the two concepts' proper understanding and treatment. The architecture of a system is the set of its principal design decisions (Taylor et al. 2009a). Architecture represents the system's blueprint, and is reflected in its key building blocks, their composition, their interplay, the resulting non-functional properties, and so on. In that sense, a given system's architecture may be well aligned with one or more existing frameworks, such that those frameworks may be used in effectively realizing that architecture. An explicit focus on system architecture yields several important benefits. For example, architectural models constructed early in a system's life cycle enable engineers to verify important system properties before significant resources are invested in constructing the (possibly problematic) system. Likewise, system adaptation, whether initiated by a human operator or by the system itself, must be explicitly "built into" and enabled by the architecture (Oreizy et al. 1999). Explicit architectural focus is also beneficial in that it allows the reuse of known solution strategies in the form of architectural styles (e.g., peer-to-peer, client-server, publish-subscribe, event-based, and so on) (Taylor et al. 2009a, Taylor et al. 2009b).

Simulation. Simulation can be used for many reasons including the in-depth study of an area, performance prediction, change analysis, "what-if" scenario evaluation, and to test new ideas about a system prior to implementation. Simulation can allow a user to view a system over time without having to build, interrupt or affect it. System dynamics simulation models incorporate feedback (causal) loops, so that complex system relationships and feedback mechanisms can be understood. These models promote "systems thinking." Simulation, including system dynamics models, can be a cost effective way to gain insights on different aspects of systems. Simulation has been utilized in many domains, including the engineering of products. A significant level of research has been done in software engineering to understand and evaluate software process dynamics, for example Madachy (2008) draws from over one hundred publications in his book Software Process Dynamics. In a similar manner, simulation can be applied to understand the systems engineering processes used from concept through disposal of a system, including in-depth analyses and assessment of options related to T&E processes and systems to be tested. Simulation may be especially helpful for analysis of unmanned and autonomous systems of systems testing due to the additional complexity inherent in these efforts.

Decision Support Tools. Decision Support Systems (DSS) refer to information systems that support organizational decision making (Keen 1978). Traditionally, DSS were tailored to the needs of individual users, but evolved to support multiple decision makers through Group Decision Support Systems (DeSanctis and Gallupe 1987) and Organizational Decision Support Systems (Carter et al. 1992). The basic architecture of a DSS consists of three components: a database, a model and a user interface. As such, research in database design, software engineering and user interface design have significantly contributed to DSS development. Furthermore, Intelligent Decision Support Systems refer to DSS that leverage artificial intelligence technologies for decision making. DSS have found numerous applications that include financial planning systems, clinical DSS for medical diagnostics, and executive decision making systems for performance analysis, resource allocation, and planning. While traditional DSS are often tailored to support specific types of organizational decision making, recent work has proposed an Integrated Decision Support Environment to "integrate capabilities from a set of systems to configure a computer environment for varied decisions under varied situations" (Lui et al. 2008). An important challenge that needs to be addressed in the T&E domain is the development of DSS at the organizational level that can support joint testing efforts and varying stakeholder needs.

Real Options. The term real option was introduced by Myers (1984) and is commonly defined as the right, but not the obligation, to take an action in the future. Real options analysis (Copeland and Antikarov 2001) has been used for decision making under uncertainty in the context of numerous applications. These applications include capital investment decisions (Dixit and Pindyck 1994, Mun 2006) ranging from IT investments (Benaroch 2006) to the valuation of R&D (Tsui 2005) and intellectual property (Bloom and Van Reenen 2002). Furthermore, real options analysis has been applied to system design decisions (de Neufville 2003, Cardin et al. 2007). More recent work (Mikaelian 2009) presents an approach to holistic, model based identification and valuation of real options. A logical coupled dependency structure matrix was introduced by Mikaelian (2009) for the identification of real options. This approach can be applied to support strategic test planning decisions for unmanned and autonomous systems in a system of systems environment. An important challenge is the identification of the role of real options in an Organizational Decision Support System for joint testing.

Dialog with Communities of Practice

One of the challenges identified in Table 1 is the lack of a knowledge base for unmanned and autonomous system testing. The available knowledge base for unmanned and autonomous systems of systems T&E approaches is limited and still to be defined in many cases given the relatively recent emergence of UASs. In order to increase the knowledge base and better understand the applicability of innovative ideas, methods, and techniques, it will also be extremely important to meet and dialog with domain experts and stakeholders in the T&E and UAST community. UAST will not be able to succeed in offering solutions unless the testing community is involved (Macias 2008). There are also multiple organizations that may be able to provide assistance and support with the previously identified challenges. These groups include ITEA, the software test community, INCOSE, the robotics community, and NIST, among others.

ITEA. The International Test and Evaluation Association (ITEA) is a not-for-profit educational organization that focuses on furthering the exchange of technical information in the field of T&E.

Its mission is to advance the field of T&E worldwide in government, industry and academia (ITEA 2009). The organization hosts an annual symposium, short courses, workshops and conferences.

Software Test Community. The software test community is widespread and has multiple interest groups, professional organizations, conferences, and certifications. The increasing integration of systems and software engineering (Boehm 2006) makes it essential to apply lessons already learned in software engineering to systems engineering. Given the trend of increasing software content in systems, it is particularly important to continue to address the integration of these two critical disciplines and leverage lessons learned from software engineering for the benefit of systems engineering, and, in this case, for systems of systems T&E. The software test community may have concepts, methods, and techniques that may be available or are expected to evolve over time and which can be applied to address current and forecasted UAST challenges.

INCOSE. There is a growing realization that systems engineering is necessary for the management of complex systems development throughout the life cycle from concept through disposal. The International Council on Systems Engineering (INCOSE) is a professional organization founded to develop and disseminate the interdisciplinary principles and practices that enable successful systems to be realized (INCOSE 2009). INCOSE has multiple and, in many cases, very active working groups. A working group has recently been created for Autonomous System Test and Evaluation and a working group exists for Verification and Validation. Many large systems contractors and integrators as well as government groups, academia and employees from each of these groups are members of INCOSE. Therefore, INCOSE represents a significant source of systems (and systems of systems) experts and knowledge. This community can represent a rich source of new ideas to tap into for the benefit of the UAST community.

Robotics Community. The robotics community will provide core knowledge related to testing unmanned and autonomous systems. It will be important to seek various organizations' contributions and understand the evolution of test and evaluation in this community.

NIST. The National Institute of Science and Technology (NIST) is developing foundations for metrics and standards of intelligent systems (NIST 2009a). NIST has, with DoD participation, worked to establish terminology for autonomous capabilities (OUSD 2009). NIST has workshops for intelligent systems that includes sessions specific to the T&E of UASs (NIST 2009b). Standards and guidelines developed by NIST for intelligent systems will provide key inputs for the development and testing of these systems.

Conclusions and Future Work

Unmanned and autonomous systems bring new challenges to the DoD's T&E community. Test and evaluation of UASs is more complicated than traditional testing of manned systems for multiple reasons. At a minimum, these complications include addressing increasingly autonomous systems, the need to test integrated systems of systems in joint military operational testing environments, systems with growing complexity and capabilities that may be at different maturity levels, and the need to consider emergent properties, desired as well as undesired and sometimes unpredictable. The UAST community has identified challenges related to the T&E of UASs operating in a SoS environment. This paper presents various approaches for addressing these challenges including current DoD investments, utilizing methods from other disciplines, and dialog with T&E stakeholders as well as others who may be able to provide helpful recommendations and insights. PATFrame, which includes an innovative prescriptive and adaptive testing framework and decision support system, is introduced.

Efforts have been started and significant future work is planned by the joint team of MIT, USC, UTA, and SoftStar Systems to develop the proposed testing framework and decision support system technology. The framework and decision support system offer the promise of helping the UAST community address key identified challenges and evolving needs.

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