Testing Network-Enabled Capabilities in a Realistic Operational Environment

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ABSTRACT

In the United States, the Joint Capabilities Integration and Development System (JCIDS) is transforming the way the Department of Defense is acquiring new systems and capabilities. Effective test and evaluation is becoming more difficult across the entire acquisition process as individual platforms become part of complex, networked systems of systems that must interoperate and depend upon each other on a battlefield made up of air, land and maritime forces. In the future all programs, regardless of their acquisition category, will be required to demonstrate their joint capability early and through-out their respective development cycles. This new way of doing business presents many challenges to the test and evaluation community. To partially address this problem, the Director, Operational Test and Evaluation, chartered the Joint Test and Evaluation Methodology (JTEM) project in 2006 to develop and validate methods and processes for designing tests in a joint mission environment. Specifically, the JTEM project was directed to develop, test, and evaluate methods and processes for defining and using a distributed environment employing live, virtual, and constructive models and simulations. This paper will discuss the Capability Test Methodology developed by JTEM, along with an underlying analytic framework to determine joint mission effectiveness, as well as the results of applying the CTM to a notional set of network-centric systems during a distributed test event in 2007. Many of the methods, processes, and analytic techniques used by the methodology can be readily extended to incorporate coalition and NATO forces as well. This paper will also include a summary of some of the challenges faced so far in developing these methods and processes, as many of the lessons learned may be applicable to NATO testing as well.

1.0 BACKGROUND

Traditional methodologies for developing and testing military systems in the United States have been adequate for (1) verifying specification compliance for individual systems, and (2) determining the operational effectiveness and suitability of a system within a single Service environment. However, the Department of Defense is moving away from traditional "threat-based" approaches, where individual weapon systems were developed to counteract similar threat systems. These new "capability-based" approaches to acquiring future weapons envision multiple systems that act in a networked environment as an overall "system of systems," interacting and interoperating with each other in a complex joint mission environment that includes land, air, and maritime forces operating simultaneously. This new capability-based approach is implemented in the Joint Capabilities Integration and Development System (JCIDS) [1]. JCIDS also recognizes that, in addition to material aspects of a weapon system, doctrine, organization, training, leadership, personnel, and facility (DOTLPF) contributions to an overall capability must now be taken into account much earlier in the development process than in the past. Overall, the department's long-term strategy calls for evaluations of joint system effectiveness throughout all phases of a military system's development and deployment; in short, to "test as we fight."

The resulting complex environment -- the number of possible system and network combinations and interactions, along with multiple environmental conditions, and DOTLPF aspects -- creates an exponential explosion of possible test conditions. It will be very difficult to collect enough test data to try out every possible combination of environmental conditions, modes of operation, and systems operating conditions for a networked system of systems operating in a realistic joint environment. In addition, replicating the realistic joint environment will be very challenging, as the ability to assemble all required assets at a single test location will be nearly impossible due to scheduling constraints and resource availability.

A key component of testing new systems in a realistic joint environment is a modern networking infrastructure that connects distributed live systems with virtual (human-in-the-loop and hardware-in-the loop) and constructive (pure computer software) simulations. These environments are referred to as live, virtual, constructive distributed environments (LVC-DE) and are similar to the training environments now employed on a routine basis in the department for joint training.

Recognizing the challenges of testing future combat systems in a realistic joint mission environment, the Director, Operational Test and Evaluation (DOT&E), completed a roadmap [2] that outlined challenges in (1) test infrastructure and standards, (2) methods and processes, and (3) policy. Subsequently, in March 2006, DOT&E chartered the Joint Test and Evaluation Methodology (JTEM) Joint Test and Evaluation Project to focus on the Roadmap methods and processes area. Specifically, JTEM was chartered to develop, test and evaluate a methodology for defining and using a LVC-DE for testing to evaluate individual system performance and joint mission effectiveness.

2.0 THE CAPABILITY TEST METHODOLOGY

The JTEM project has developed the Capability Test Methodology (CTM), which is a collection of recommended best practices for designing a test of a system or system of system in a complex joint environment. CTM version 2.0 is depicted in Figure 1. The CTM is the foundation for a series of guides, templates, handbooks, and training courses the project will ultimately deliver to test organizations and acquisition program managers. Version 2.0 consists of six steps and fourteen processes. The CTM is designed to augment, not replace, existing test methods and processes, and takes into account the unique aspects of testing joint, networked systems in a LVC-DE. As such, the CTM closely parallels existing test processes used within the US Department of Defense. A detailed explanation of each step is beyond the scope of this paper, but each step is described briefly here.

Step 0 focuses on defining an evaluation strategy for the overall test. The key step in this process is describing the overall Joint Operational Context for Test (JOC-T) that will later be used to define the specific elements that make up the LVC-DE. This JOC-T includes a detailed description of the system under test, supporting systems, the expected operating environment, threat forces, and key system interactions and information exchanges required to complete a particular task or mission. In Step 1, the program manager for a system outlines the details of a particular test or set of tests in a Program Introduction Document, which he uses to communicate his requirements to a test range. The test range then uses that document to produce a Statement of Capability, which is the starting point for determining what resources will be used to conduct the test and what data will be collected. Step 2 produces distributed test plans that are compilations of current

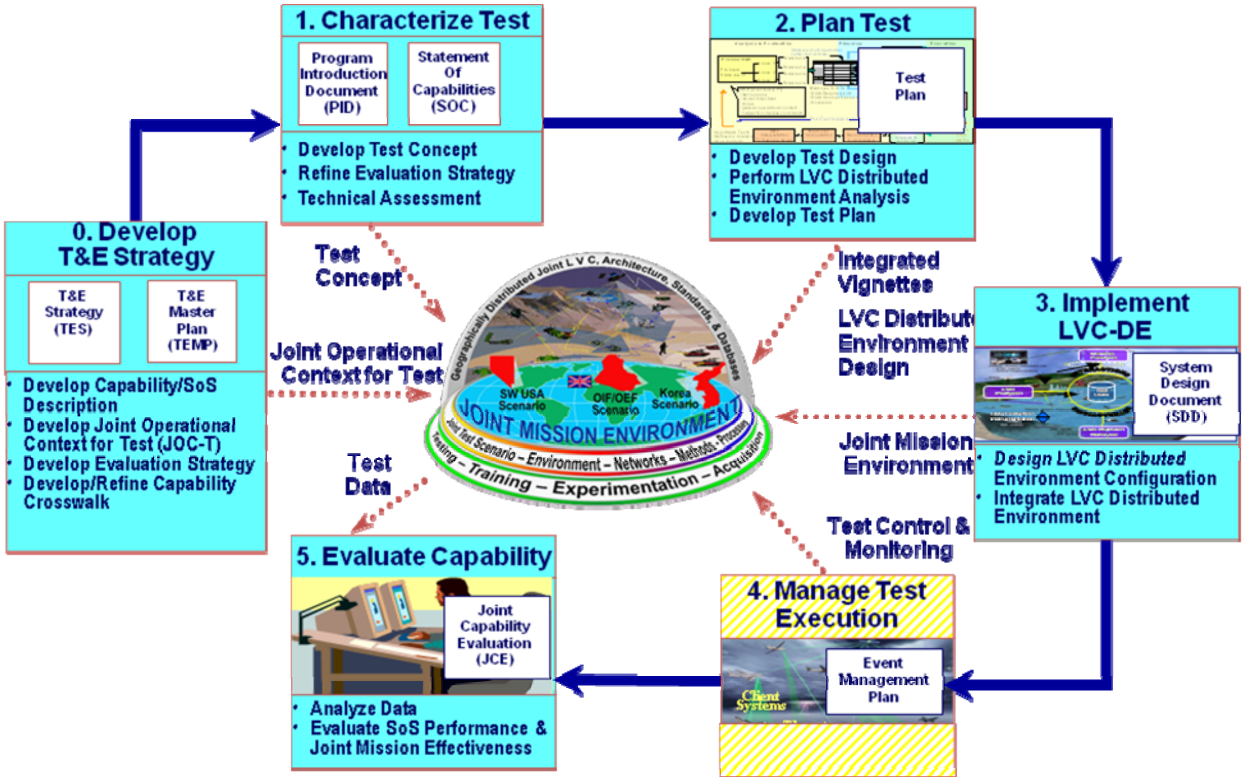

Figure 1: The Capability Test Methodology, Version 2.0

individual test plans, with the addition of distributed and joint elements. During this test planning phase, early test concepts are developed into more detailed test plans. Test planning processes include test trial/vignette selection, refining the LVC distributed test environment required, and synthesizing these activities into an overall test plan. During CTM steps 3, 4, and 5 joint mission environments are assembled, then used, to support multiple test plans. Step 3 is concerned with technical systems engineering activities for automatic distributed LVC-DE implementation. These processes include the design of distributed configurations, assembly of distributed components, and integration of components into a distributed test range that meets customer requirements. In CTM Step 4, Manage Test Execution, distributed tests are conducted according to local procedures, and data are collected. This phase produces test data for customers and reusable information for future joint mission environments. Though joint mission environments are assembled to support multiple customers, tests do not have to be run concurrently. Sometimes, individual customers may separately schedule only those parts of the joint mission environment they need to meet their own objectives for testing in a joint environment. Other times, multiple customers may share a joint mission environment at the same time for convenience or other reasons. In the final step, Evaluate Capability, data are processed, analyzed, and evaluated. Step 5 includes evaluations of joint mission effectiveness and contributions of individual systems to joint missions.

3.0 THE ANALYTIC FRAMEWORK

In addition to the CTM, JTEM has developed a supporting measures framework that establishes appropriate measures to support the evaluation of a system or system of systems within a capabilities context. This measures framework is depicted in Figure 2. The measures framework is based on the JCIDS definition of a capability, "the ability to achieve a desired effect under specified standards and conditions through a combination of ways and means to perform a set of tasks."

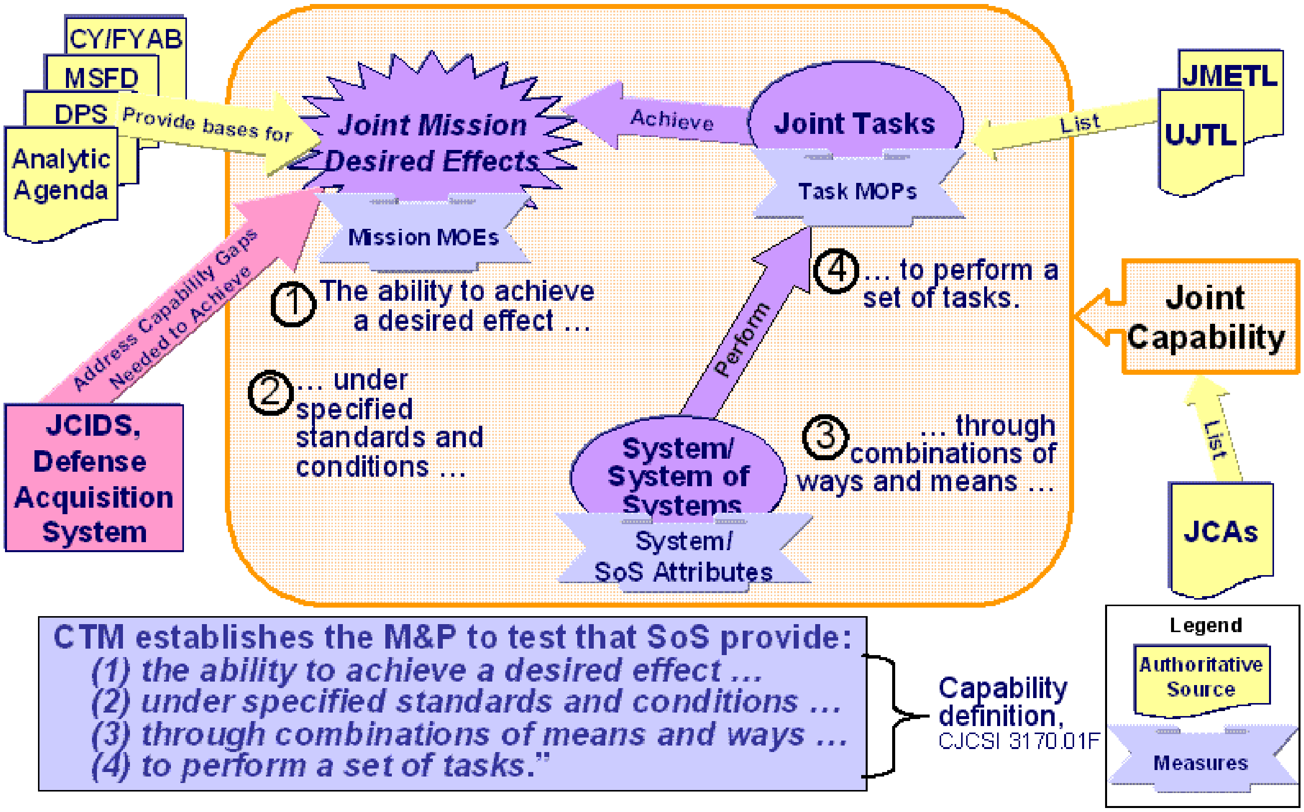

Figure 2: A Capabilities-Based Measures Framework

In this framework, measures of effectiveness are established at the mission level, based on the joint mission effects that the combatant commander desires to achieve. These joint mission desired effects (number 1 in the series of steps in Figure 2) are documented through a compilation of products that make up the "Analytic Agenda," a department-wide framework for analyzing force structure requirements. The products used to document the desired effects include the Defense Planning Scenarios (DPS), a series of scenarios that describe the range of military operations that combatant commanders must be prepared for, along with the operating forces and threats that are described in the Multi-Service Force Deployment (MSFD) database and the Current Year (CY) and Future Year Analytic Baselines (FYAB). These desired effects must be achieved under specified standards and conditions (Step 2 in Figure 2) using systems, systems of systems, and the supporting DOTLPF aspects, which make up the combinations of ways and means in step 3 of Figure 2. These systems and systems of systems have various performance attributes associated with them, e.g., the launch range of an aircraft, or the time to disseminate information to the battlefield from a higher echelon headquarters. The systems and systems of systems ultimately are used to perform a set of joint tasks (step 4 in Figure 2) which achieve the joint mission desired effects. In the measures framework, measures of performance are used to describe the overall performance desired for each particular task. The joint tasks are described through the Universal Joint Task List (UJTL) and the Joint Mission Essential Tasks List (JMETL) along with the specified standards and conditions depicted in step 2 in Figure 2. The UJTL and JMETL also have corresponding Service tasks lists which support them. Although mission measures of effectiveness will be very difficult to capture directly during tests in a joint environment, the task-level measures of performance and the system and system of system attributes can be readily measured. Analysis and combat modelling can then be used to determine overall measures of effectiveness for the joint mission desired effects.

4.0 APPLYING THE CTM TO NETWORK-ENABLED CAPABILITIES TESTING

This section describes the application of an earlier version of the CTM (version 1.0) to a recent test that involved constructive models of network-enabled weapons operating in a complex joint environment. The constructive models used were a depiction of notional weapon system capabilities, and are not representative of the capabilities of any actual systems under development by the US. The intent of the test was to illustrate the application of the CTM and the type of questions that can be answered by testing with early constructive models in realistic joint environments. The intent of the test was also to show the value of tests where live operators can interact with virtual and constructive models, and demonstrate how the interdependence of material and non-material elements can be addressed throughout the acquisition life cycle.

4.1 Test Objectives and Test Item Descriptions

The overall notional test objective was to evaluate the system performance of an air-launched network-enabled weapon (NEW) and a ground-based fire support platform (FSP) when those weapon systems were employed together as participating elements in a networked system of systems. The particular joint mission of interest was joint fire support [3] to include aspects of joint close air support [4]. The joint mission effectiveness measure of effectiveness was the ability to deny employment of enemy forces (i.e., timeliness of the attacks). The messages exchanged via the Link-16 datalink were the focus of the system evaluations, and the tactics, techniques, and procedures (TTPs) for in-flight handoff of the NEW control were the focus of the non-material evaluation. Specific objectives included (1) determining if weapon design or joint TTP modifications could improve overall joint mission effectiveness, and (2) determining the ability of pilots and joint terminal attack controllers (JTAC) to perform NEW handoff functions in a joint mission environment.

The notional air-launched NEW was a sub-500 pound class guided bomb with data link capabilities. The weapon had several guidance modes for attacking movable targets in adverse weather in high-threat environments. The data link mode with third party targeting used basic GPS guidance with target coordinates updated by ground-based elements after weapon release. Update coordinates were sent via Link-16 or UHF. Other guidance modes included target coordinate update from the releasing aircraft and a terminal guidance mode. In third party targeting mode, the aircraft received initial target locations and ground-element identification information. Weapons periodically sent status information across Link-16 and would abort if commanded by their controlling element. The constructive model used in the tests also included nominal weapon flying qualities and specification-compliant data-link message simulations.

The notional ground-launched FSP system consisted of a family of missiles and a deployable, platform-independent launch unit with a self-contained tactical fire control capability. Each launch unit consisted of a computer-communications module and some number of precision, GPS-guided missiles for either direct or loitering attacks. This series of tests used only direct-attack missiles, which were modular, multi-mission, guided weapons with two trajectories – fast-attack and boost-glide. The missiles received target information prior to launch, and could receive and respond to target location updates during flight. The missiles also could support laser-designated, laser-anointed, and autonomous operation modes, and could transmit near-real-time information in the form of target imagery prior to impact. The constructive model used in these tests could only receive and guide to a pre-launch set of target coordinates following nominal boost-glide trajectory.

4.2 Test Scenario, Vignette, and Trials

The test vignette was a relatively brief sequence of operational actions during which an air-launched NEW and a ground-launched FSP system delivered joint fires capabilities. The NEW system generally followed current joint close air support procedures. The FSP system generally followed current joint fire support procedures. Airspace was controlled according to current joint doctrine using a combination of positive and procedural control measures [5]. In the overall joint operational context for this test, joint fires were assumed to be assisting forces (air, land, maritime, and special operations), joint air operations, and joint interdiction operations in a major combat operation scenario [6]. The distributed live, virtual, and constructive implementation of the test vignette is illustrated in Figure 3.

Eight trials of the vignette were conducted under different conditions, as shown in Table 1. During setup, the test director assigned airspace to either CAS or fire support (depending on trial conditions), reflecting preplanned assignments in an airspace control order (ACO). Forward Observers supported FSP activity, and were embedded with Army maneuver forces. Air Force JTACs were positioned with supporting forces, not part of the maneuver group. CAS aircraft started in an orbit under Airborne Warning and Control System (AWACS) control. Trials where FSP was first in order began with a surveillance aircraft detecting vehicle movement and generating Link-16 ground track messages. In response, the fire support element (FSE) directed a reconnaissance, surveillance, and target acquisition (RSTA) unit to investigate. The RSTA unit found a scud transporter erector launcher (TEL) with an armor unit in close proximity. A forward observer identified the scud TEL and called for fire support. The brigade FSE generated either a small or large airspace control volume (depending on trial conditions) in an airspace control measure request (ACMREQ) and passed it to the Combined Air Operations Center (CAOC). After approval of the request in the CAOC, an airspace coordination measure (ACM) was disseminated to the FSE, Air Support Operations Center (ASOC), and AWACS. The brigade FSE then sent a fire order through the fires battalion to the FSP battery. The FSP Launch Unit battery targeted the scud TEL and fired one missile.

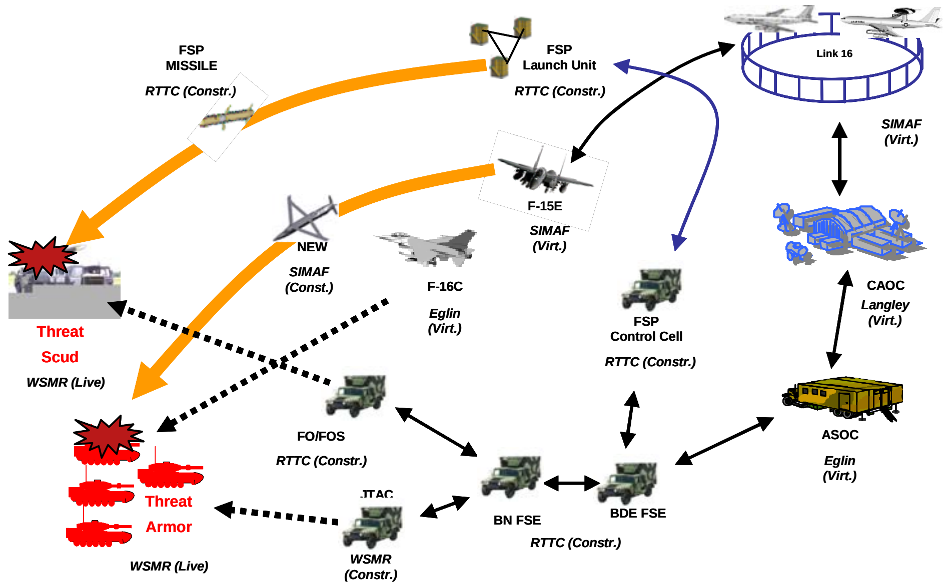

Figure 3: Live, virtual, constructive distributed environment for the test vignette

Table 1: Test trials and conditions

Trial	Airspace Control Volume	Initial Airspace Assignment	First in Order	Third Party Source
1	Small	JCAS	FSP	JTAC
2	Small	JCAS	NEW	Second aircraft
3	Small	Fire support	FSP	Second aircraft
4	Small	Fire support	NEW	JTAC
5	Large	JCAS	FSP	Second aircraft
6	Large	JCAS	NEW	JTAC
7	Large	Fire support	FSP	JTAC
8	Large	Fire support	NEW	Second aircraft

At missile impact, a JTAC requested CAS against an armor unit. The brigade FSE concurred with the air support request (ASR) and sent an ACMREQ to the CAOC changing the artillery fire zone to a restricted fire zone. The CAOC then approved the ACMREQ and ASR. CAS aircraft engaged the armor unit with a NEW. As soon as possible after weapon release, the launching aircraft handed off NEW control to either the JTAC or a second aircraft (depending on trial conditions) to provide a third party source for target coordinate updates. The third party source sent updated target coordinates to the NEW as soon as possible after handoff. Trials where the NEW was first in order began with a JTAC requesting CAS against an armor unit. Then at NEW impact a surveillance aircraft detected vehicle movement and generated Link-16 ground track messages to initiate fire support actions as described above. The experimental design shown in Table 1 is an eight-trial, one-half fraction of a 16-trial full factorial design with four factors at two levels [7].

4.3 Test Results

In this test, joint mission effectiveness was considered to be directly related to the overall task performance, which was measured by the timeliness of the attacks. Trials with longer times from initial requests to final weapon impact were generally considered less effective, all else being equal, than trials with shorter times. A detailed analysis of the results is beyond the scope of this paper, but can be found in reference [8]. A short summary of one aspect of the test results is presented here. Figure 4 contains a measure of NEW contributions to joint mission effectiveness across all eight test trials and the half-normal plot of factor effects calculated from these measurements. There is some evidence that "Third Party Source" has a significant effect. The plot in Figure 5 shows that weapons were delivered to targets faster when the NEW was handed off to a JTAC. Pilots of CAS aircraft observed this was at least partially because the JTAC constituted the best sensor in this test vignette.

Trial	Airspace Control Volume	Initial Airspace Assignment	First in Order	Third Party Source	Time from CAS Request to Impact (sec)
1	Small	JCAS	FSP	JTAC	823
2	Small	JCAS	NEW	Second aircraft	1129
3	Small	Fire support	FSP	Second aircraft	1554
4	Small	Fire support	NEW	JTAC	985
5	Large	JCAS	FSP	Second aircraft	1254
6	Large	JCAS	NEW	JTAC	785
7	Large	Fire support	FSP	JTAC	740
8	Large	Fire support	NEW	Second aircraft	1039

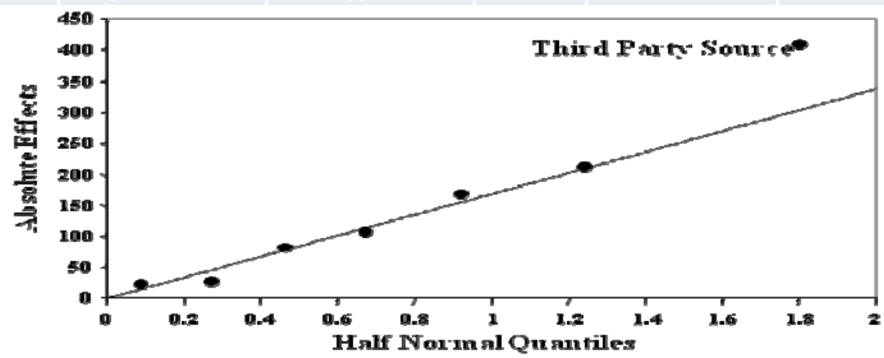

Figure 4: Effect of test conditions on NEW contribution to joint mission effectiveness

In aircraft-to-aircraft handoffs, the launching aircraft handed over NEW control to a second aircraft that was tracking the target with a targeting pod. The pilot of the second aircraft usually needed additional time to find and verify the target with the pod. Thus the contribution of the test NEW design to joint mission effectiveness can depend on a non-material component of the weapon system. Stated another way, the joint mission effectiveness of the tested NEW design is not robust to "Third Party Source." The NEW contribution joint mission effectiveness could be improved if the system-of-systems were modified to allow faster NEW handoffs between aircraft.

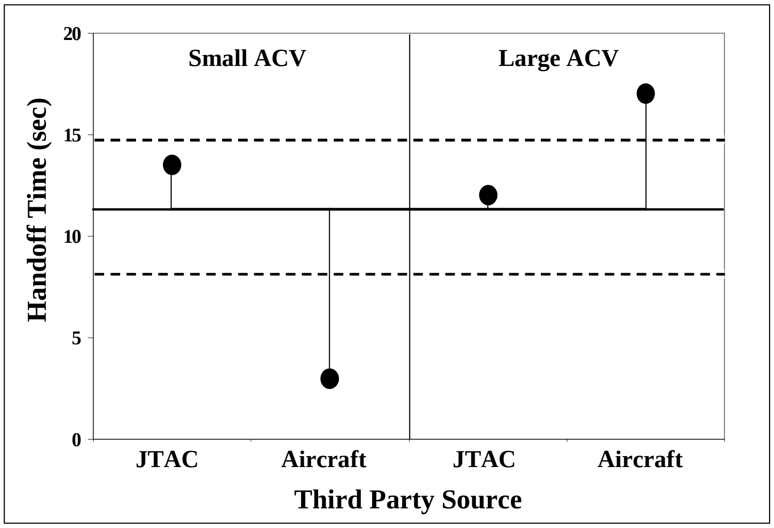

Figure 5: Analysis of means plot for "Third Party Source" main effect

4.4 Test Conclusions

The results of this test of networked systems demonstrated the tremendous potential value of testing in a joint environment early in the acquisition life cycle. The constructive models tested showed how well weapon designs could deliver their required joint capabilities, while test results identified several possible improvements. Because live operators could interact with these early constructive models, they were able to discover shortcomings in systems and systems-of-systems that limited joint mission effectiveness. The live operators also identified non-material improvement areas, including interdependencies between airspace control doctrine and network-enabled weapons tactics, techniques, and procedures.

5.0 CHALLENGES, LESSONS LEARNED, AND NEXT STEPS

Although the limited test described above shows the potential that can be realized from testing networked systems of systems in a realistic operational environment, there are still many challenges to doing so on a regular basis. These challenges fall into the categories of: (1) agreed to measures of performance and effectiveness across multiple joint missions, (2) persistence of the test environment used for testing, and (3) analysis and data management techniques to deal with the increasing complexity of planning tests and evaluating the results of tests of net-centric systems.

Although challenge #1 can be dealt with by establish an agreed-to framework such as that suggested in Figure

2, there remains a substantial amount of work to develop appropriate measures at each required level and to determine the supporting test infrastructure to collect the test data to support such measures. However, the tasks described in the UJTL, JMETL, and supporting Service task lists tend to remain stable over time, and decades of disciplined testing have contributed to a fairly stable body of system level measures. What is still needed is a consistent set of measures for the tasks that can be related to system measures and overall joint mission effectiveness.

The persistence of the distributed test environment is another challenge. If testing in a networked, joint environment is to be accomplished on a regular basis, the department needs some sort of “standing” test capability that exists similar to the existing test ranges and facilities today. The infrastructure to do a distributed test in a joint environment today is very fragmented and Service-oriented. The ability to bring together large numbers of systems distributed across multiple test ranges and simulation or test facilities is currently very limited. Some of the issues involved, just to name a few, include multi-level security; persistent connectivity across multiple Service domains; integration of contractor facilities; protection of contractor intellectual property; verification, validation, and accreditation of the distributed environment; data collection, distribution and archiving; and environment repeatability.

New analytic techniques are also needed to deal with increasingly complex environments. Combat modellers have often attempted to cope with increasing complexity by building more detailed models of their systems. This technique can work for systems that function within a linear operating range, have well-known operating characteristics, conform to well-developed physical theories, and do not have significant interaction with other systems. However, networked systems of systems by definition will have significant interactions with each other and with their operating environments. And introducing non-linear and less understood aspects of human behaviours, training levels, and organizational structures to represent the DOTLPF aspects of a capability further complicates the operating environment. Building high-resolution models to represent these aspects across a reasonable set of environments is at best daunting and probably hopeless for any realistic combat system of systems.

Even if we could build a high-fidelity joint mission-level model of our complex system of systems, our ability to use it to investigate the overall test envelope would still be very limited due to the “highly dimensional problem” posed – the sheer number of conditions that need to be varied and the different levels required for each condition quickly results in an exponential explosion of possible test points. Even if we had models that could produce all possible outcomes, the human ability to cope with interpreting the data is very limited – current visualization tools typically break down after three or four dimensions.

Possible solutions to the above analytic problems include advanced design of experiments techniques and the application of complex adaptive systems techniques to combat modelling. Discussion of these techniques is beyond the scope of this paper, but the JTEM project is investigating these possibilities for application to future test planning techniques and to the evaluation of test data that is collected in a realistic joint mission environment.

As a result of the lessons learned from applying the earlier version of the CTM in the 2007 test event, JTEM made numerous changes and released the CTM version 2.0 depicted in Section 2.0 of this paper. This CTM is being applied and evaluated during a follow-on test event in July 2008. This test event is planned to have a battlespace with significantly more complexity than the relatively simple vignette portrayed in the 2007 event. The NEW-FSP vignette will be repeated in 2008 as only one mission thread/task being executed during the event. In addition, one customer is planning to examine test techniques for evaluating the performance and effectiveness of various networks and nodes used during the task, focusing on detection and recovery procedures when subjected to a network attack.

After completion of the 2008 test event, JTEM will update the CTM and release version 3.0 in March 2009. This is the last planned version for release under the JTEM project. However, discussions are underway to leave in place a transition organization or function that will assist customers with applying the CTM, particularly to net-enabled and command and control systems. This organization will also continue to improve the CTM and build a library of standing resources (for example, scenario definitions and measures) to assist future customers with a requirement to test in a complex joint mission environment.

6.0 CONCLUSIONS

JTEM has developed the CTM to assist with the design and execution of tests of complex, networked systems of systems in realistic operational environments. JTEM recently demonstrated the application of the CTM to a notional set of network-enabled air and ground launched weapon systems while employed in a realistic joint mission environment supporting an overall joint fire support task. While much work remains to be done to make testing in a joint environment on a routine basis a reality, the CTM and the supporting measures framework provide a good foundation for future testing. The CTM can be readily extended to include NATO and coalition systems, and enables the definition of a consistent set of measures to conduct testing of current and future net-enabled systems.

7.0 REFERENCES

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