INTRODUCTION
The use of design of experiment (DOE) and data farming techniques is critical to effectively planning, and subsequently evaluating, tests of complex adaptive systems in a joint mission environment. The Joint Test and Evaluation Methodology (JTEM) program, in conjunction with the SEED Center at the Naval Postgraduate School (NPS), and TRADOC Analysis Center-Monterey, is developing methods and processes that incorporate these techniques into the development of the "test and evaluation strategy" phase of the Capability Test Methodology (CTM). In order to structure the underlying business rules and concepts in the CTM’s evaluation thread, a Capability Evaluation Metamodel (CEM) is being developed.

The CEM measures framework consists of mission measures of effectiveness (MOE), task measures of performance (MOP), and system/system of systems (SoS) attributes. The mission MOEs assess the contribution of the system under test (SUT) and SoS capabilities to achieving the mission desired effects. Task MOPs address essential task performance related to the identified test issues (critical joint issues [CJI], critical operational issues [COI]). System/SoS attribute measures are used to evaluate the achievement of system or SoS performance across doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF). The evaluation measures for the CTM map from mission to task to attribute level is shown figure 1.

APPROACH
During IDFW 15, Team 6’s goal was to demonstrate and improve SoS test scoping and design techniques, as they pertain to capabilities supporting joint missions. We used a four-part approach to address this data farming goal:

- Characterize past and hypothetical capability design use cases, including the refinement of a hypothetical CJI and CEM test designs.
- Apply DOE techniques to initial multi-factor CEM capability designs. The DOE focus was on Nearly Orthogonal Latin Hypercube (NOLH) and Fractional Factorial Controlled Sequential Bifurcation (FFCSB) DOE techniques, which are being enhanced at the NPS.
Conduct data farming on selected factors of this efficient DOE using Tester and Pythagoras agent based simulation (ABS) models.

Conduct initial analysis of ABS results.

The following questions were addressed by Team 6 activities during IDFW 15:

- Given a past use case limited by JTEM FY07 event constraints (limited SoS composition, partial task thread), which factors are the most important to look at for testing?
- Using a hypothetical use case (FY07 event constraints removed) and a refined CJI, which factors are the most important to look at for testing?

During the workshop, Team 6 conducted "test and evaluation strategy" activities to design and focus the test space for the above stated use cases. These activities included validation of previously developed CEM concepts including CJIs with associated measures, levels, and factors for input into existing models. An iterative approach for refinement of large capability test spaces was exercised involving: developing an efficient capability design of experiment, running model designs on a high performance computing cluster, performing multivariate analysis using the JMP statistical analysis tool, and discussing model design refinement to focus on important factors. The results of this workshop provided valuable input into the development and improvement of the CTM.

For the past use case, Team 6 used version 1.0 of Tester, an agent-based model developed in the MASON framework, to perform exploratory data farming in support of JTEM's data farming for test planning effort. This data farming effort included exploring the results from a recent SoS test event, expanding the bounds of the test results, and understanding the functionality of the model at this point. An NOLH DOE was used for the past use case which included the following independent variable factors:

- Time to clear airspace
- Aircraft speed
- Air support request (ASR) approval time
- Combined Air Operations Center (CAOC) restricted fire zone (RFZ) time
- Close air support (CAS) tasking time
- CAS Joint Terminal Attack Controller (JTAC) coordination time

The dependent response variable in the past use case DOE was CAS Elapsed Time, which is an example of a task MOP in the CEM measures framework.

The following hypothetical CJI was refined by Team 6 in order to create a capability design for the hypothetical use case:

Assess Integrated Fires Command and Control (C2) task performance (for example, CAS, Fires, Dynamic Targeting) to achieve joint forcible entry operations desired effects (for example, threat ineffectiveness, Blue survivability) by an Integrated Fires SoS compositions (for example, C2 system focus, force application system enablers).

CJIs are used to assess performance pertaining to capabilities which support joint missions. A CJI for test and evaluation should be carefully structured to address key capability gaps described in joint capability documentation. The essential elements of a CJI include a capability’s essential tasks, mission desired effects, Blue SoS (across DOTMLPF), and conditions involving threat and environmental factors. CJIs should address the SoS capability to perform joint operational tasks and/or the SoS, system, or Service attribute performance.

Based on the hypothetical CJI, a set of capability test design independent variable factors were created based on the factor dimensions of the CEM Joint Operational Context for Test (JOC-T). The JOC-T describes the overall philosophy of forces operating jointly and the tactics, techniques, and procedures (TTP) to be employed to achieve effects on the battlefield by exhibiting capabilities they will not possess separately. The JOC-T should specify mission objectives (for example, mission statement, mission desired effects, mission end state), Blue forces (for example, system capability requirements, system means to implement those requirements, system operating limitations, SoS context, task organization, C2 structure, force lay down with logical groupings of primary nodes), Blue actions, environment conditions (for example, physical conditions, civil conditions, neutral forces), threat forces (for example, threat order of battle, C2 structure, systems, threat lay down), threat actions, and interactions (for example, Blue to threat, Blue to Blue, threat to threat, Blue to environment, threat to environment).

Using these JOC-T dimensions, an initial hypothetical capability test design was developed containing 37 continuous factors and 25 categorical factors for a total number of 62 possible independent variables. To perform preliminary data farming in support of hypothetical use case, the Pythagoras ABS model was used on a selected subset of the 62 possible factors that could be modeled in the current Pythagoras functionality. The DOE used for the hypothetical use case was an NOLH which included the following independent variable factors:

- Organic SA persistence
- Inorganic SA persistence
- Organic fuse radius
- Organic fuse time
- Inorganic fuse radius
- Inorganic fuse time
- Communication delay
- Sensor offset X
- Sensor offset Y

The dependent response variable in the hypothetical use case DOE was Blue survivability, which is an example of a mission MOE in the CEM measures framework.

RESULTS AND ANALYSIS

The past use case using version 1.0 of Tester produced modeling results as shown in the classification and regression tree (CART) analysis shown in figure 2. The most significant factor was the CAOC RFZ time, followed by CAS...
tasking time and ASR approval time. These three factors accounted for a 46% degradation of the CAS Elapsed Time Task MOP. This was a surprise to the majority of team members who had predicted force application factors, such as Time to clear airspace and Aircraft speed would be most significant. Instead, for this modeling implementation, C2 factors centered at the CAOC were dominant.

The hypothetical use case using the Pythagoras ABS produced modeling results as shown in the CART analysis, shown in figure 3. The most significant factor was Inorganic Situational Awareness Persistence. Inorganic is defined as external to the “organic” unit modeled in Pythagoras. Persistence relates to the duration of threat target information Inorganic Fusion Time and Organic Fusion Radius. The best case design (least Blue causalities in the mission MOE response) related to limiting clutter on the Blue situational awareness map. This was also a surprise to many team members who had predicted physics-based force application factors, such as sensor offsets, would be most important to limiting Blue casualties. Instead, for this modeling implementation, situational awareness and C2 fusion factors were dominant.

INSIGHTS AND RECOMMENDATIONS

Team 6 insights included the need to further expand DOE parameters for capability testing and that the importance of non-materiel C2 factors was underestimated in the team’s ABS results. Another surprise during IDFW 15 was the fact that Aloe Vera is more than just lotion; it also comes in yogurt form. Takeaways for the CTM included the benefits of applying hybrid DOE approaches, successful demonstrations of an iterative design – model/scenario development – analysis approach, and the need for supporting tools to enable data farming as part of CTM capability test design refinement and evaluation.

Recommendations from IDFW 15 Team 6 activities center on enhancement of data farming techniques for further application to capability based assessment. Specifically, enhancements to the Tester and Pythagoras ABS models are recommended for higher fidelity, more efficient capability explorations. These enhancements involve both ABS functionality, as well the automation of scenario input and MOE output analysis. The refinement of DOE techniques for large factor, multiple response designs is also identified. Developing functionality for guided selections of appropriate DOE techniques is also highlighted by the team as a promising way ahead, based on initial results. Follow-on efforts include the incorporation of data farming approaches into the CTM version 2.0 and 3.0, potentially including efficient design of experiments, the use of computing clusters, and the iterative data farming process. The intent is to explore enhanced DOE techniques and models at IDFW 16. Both use case explorations, in addition to providing data for analysis, helped in the development of the data farming infrastructure for the evolving CTM development by JTEM and its partners.