Use of Modeling and Simulation in Software TRL Evaluations

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ABSTRACT

The challenge of the AMRDEC JAMUS 08 experiment involved developing a capability to test and evaluate the maturity of the Rapid Battlespace Deconfliction (RBD) capability in the Future Combat System (FCS) Battle Command Systems (BCS) in a relevant end-to-end environment for a software Technology Readiness Level 6 (TRL-6) evaluation.

The AMRDEC team met this challenge by integrating OneSAF 2.1 with SoSCOE 2.1 Standard Edition. Rather than using typical interoperability protocols such as DIS or HLA for the integration, the team utilized SoSCOE Interface Definition Language (IDL) to build the interfaces between OneSAF and RBD, the unit under test. This resulted in an interface between the simulation and the unit under test that completely mimicked the actual interfaces.

This paper describes the demands on the simulation for network fires, data collection and visualization, and run-time monitoring. In addition, the paper discusses the lessons learned in developing the evaluation capability used for the TRL-6 Demonstration. Specific details of the problems encountered, configuration management, and VV&A analysis are also covered.

ABOUT THE AUTHORS

Gene Shreve began his college career as a music major at Santa Barbara City College in Santa Barbara, CA, before switching to aeronautical engineering at Cal Poly San Luis Obispo. In 2002 Gene received a master's degree in software engineering from Southern Poly in Marietta, GA. Gene has 17 years experience in engineering and software development. For the past 4 plus years, Gene has led a team of Modeling & Simulation developers for SAIC in support of the AMRDEC APEX labs in Huntsville, AL.

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Monte Porter is a certified M&S Professional and has over 20 years experience in integration simulations to support C4I experimentation and is the primary developer of the Intelligent Exercise Monitor.

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BACKGROUND

The Future Combat System Battle Command Systems (FCS BCS) Rapid Battlespace Deconfliction (RBD) capability was identified as Critical Technology Element twelve (CTE 12). Therefore, the RBD capability was required to have matured to a software TRL-6 prior to the FCS System of Systems (SoS) Preliminary Design Review (PDR) in the Spring of 2009. Qualifying RBD for a software TRL-6 entailed demonstrating the services that comprised the RBD capabilities in a relevant end-to-end environment. Table 1 provides the definition for the software TRL-6. [DoD Technology Readiness Assessment (TRA) Deskbook, May 2005].

The responsibility of the AMRDEC Joint Aviation Missile & Unmanned Systems (JAMUS) 08 experimentation team was to evaluate the RBD capability for the following assessment objectives:

- **Assessment Objective 1 (AO1) – Airspace Integration**: The RBD software will evaluate proposed flight plans for integration into the airspace management plan. It will identify conflicts in and out of tolerance or where there are no conflicts.
- **Assessment Objective 2 (AO2) – Battlespace Deconfliction**: Demonstrate that RBD can deconflict Battlespace Objects (BSOs) against Airspace Control Measures (ACMs) and fire missions within the Future Brigade Combat Team (FBCT) Battle Space.

Once the assessment objectives were defined, the team decomposed them into the following qualification criteria:

- Conducts BSO-ACM conflict checks and notifies the operator
- Provides the ability to integrate and deconflict airspace
- Assesses weapon-target pairing solutions for conflicts against BSOs, terrain, and Control Measures and identifies the deconflicted solutions
- Synchronizes ACMs within the FCS Brigade Combat Team (BCT)

These four qualification criteria were used to determine the maturity of the RBD capability. The challenges for the experimentation team were to isolate just the services that comprised the RBD capability (the unit under test) from the rest of FCS BCS and to develop a relevant environment that accurately simulated a future force operational environment and which also stimulated the RBD services.

TRL	Definition	Description	Supporting Information
6	Module and/or subsystem validation in a relevant end-to-end environment.	Level at which the engineering feasibility of a software technology is demonstrated. This level extends to laboratory prototype implementations on full-scale realistic problems in which the software technology is partially integrated with existing hardware/software systems.	Results from laboratory testing of a prototype package that is near the desired configuration in terms of performance, including physical, logical, data, and security interfaces. Comparisons between tested environment and operational environment analytically understood. Analysis and test measurements quantifying contribution to system-wide requirements such as throughput, scalability, and reliability. Analysis of human-computer (user environment) begun.

Table 1 Software TRL-6 Definition

METHODOLOGY & APPROACH

In order to isolate the RBD services, the team first had to identify them. This entailed a "deep dive" review of the FCS BCS operational threads (UML collaboration diagrams) identifying any service that was needed in order to satisfy the RBD TRL-6 qualification criteria. This process was extremely tedious but straight forward. However, defining the relevant environment proved to be extremely difficult because the term "relevant environment" is ambiguous. For example, there was much debate as to whether or not to include a Precision Attack Munition (PAM) or any Joint Forces in the scenario.

In an attempt to remove some of the ambiguity of relevant environment, the team adopted a Use Case methodology. Twelve demonstration use cases were composed which defined what the relevant environment and RBD had to do in the demonstration. The use cases defined the number and types of entities, the terrain, entity update rates, and the operational tactics to be performed. These use cases proved to be a valuable tool because not only did they define the relevant environment, they drove the development of the test case procedures for the demonstration. Furthermore, they greatly assisted the VV&A effort because they provided the operational context against which the relevant (simulation) environment was to be measured and they completely described all the tasks the demonstration had to perform.

With the aid of a requirements management tool (Caliber RM), the team traced each assessment objective to one or more qualification criteria and thus to one or more use cases and Measures of Merit (MOMs). Each use case was traced to one or more test cases. This allowed the team to explicitly illustrate to the FCS senior leaders how each assessment objective would be measured.

Demonstration Architecture

As the use cases began to mature and the team understood what was needed, the demonstration architecture began to solidify. In order to conduct an end-to-end evaluation of the RBD capability, the team needed to stimulate the RBD services with:

- Targets being identified by UAVs, ground sensors and helicopters
- Blue battlespace objects (BSOs) data, continually updated at a specified rate
- Ready and available Effector (logistic) data
- Indirect Fire Missions
- Airspace management plans

As shown in Figure 1, OneSAF 2.1 was used as the primary simulation. Twelve different scenarios were used in the demonstration with the largest scenario containing approximately 230 entities. However, the majority of the scenarios had less than 10 entities in order to reduce the amount of data collected and to fault isolate the unit under test.

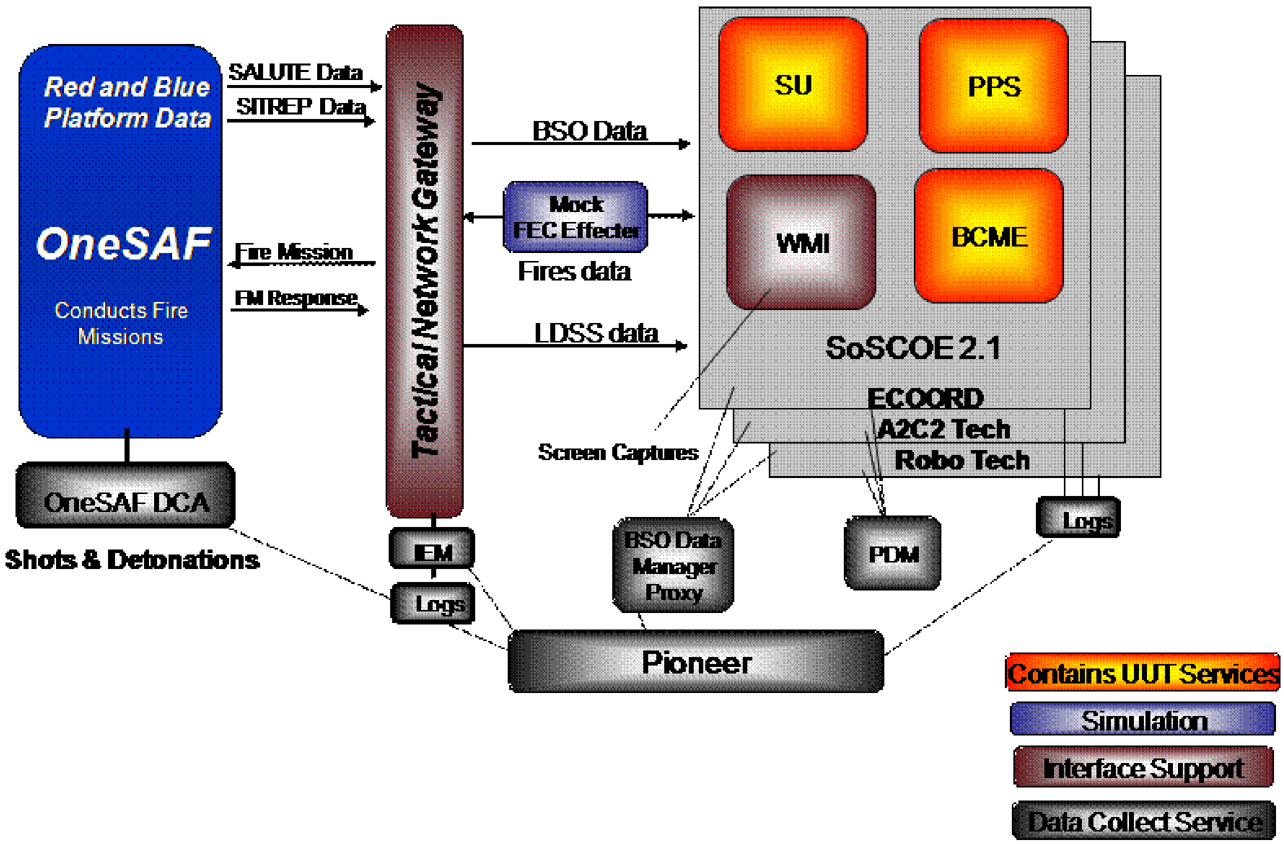

Figure 1 JAMUS 08 RBD Demonstration Architecture

At the heart of the architecture was the OneSAF Tactical Network Gateway (TNG). In cooperation with the FCS Lead System Integrator (LSI), the demonstration team integrated OneSAF 2.1 with the System Of System Common Operating Environment (SOSCOE) Standard Edition 2.1. Using the SOSCOE Interface Definition Language (IDL) obtained from the One Team Partners, the team created interfaces to the Situational Understanding (SU) services and the Plan & Preparation Services (PPS) that completely mimicked the actual interfaces. In other words, the battle command software did not require any modifications in order to be stimulated by OneSAF. For example, in the threshold system BSO data is passed to SU from a Level One Fusion (L1F) service. In the demonstration, the OneSAF TNG served as a surrogate L1F service but it appeared to SU as though it was the real service. This gave great credibility to the relevant environment debate mentioned earlier. Figure 2 illustrates the OneSAF components that were needed for the TNG to work properly. As shown in Figure 2, the TNG was actually comprised of two primary components: a OneSAF composition and a SOSCOE application. The OneSAF composition was designed to be able to extract all blue force and red force (once they were sensed) entities from the OneSAF Object Database (ODM). In addition, it understood how to retrieve entity state data such as ammo load and health upon request and how to initiate approved fire missions. The SOSCOE component was responsible for the actual interface to battle command. It also had the responsibility of controlling the BSO update rate. Abstracting the BSO update out of OneSAF allowed the demonstration team to easily control how fast blue BSO information was passed to battle command ensuring the adherence to relevant environment requirements.

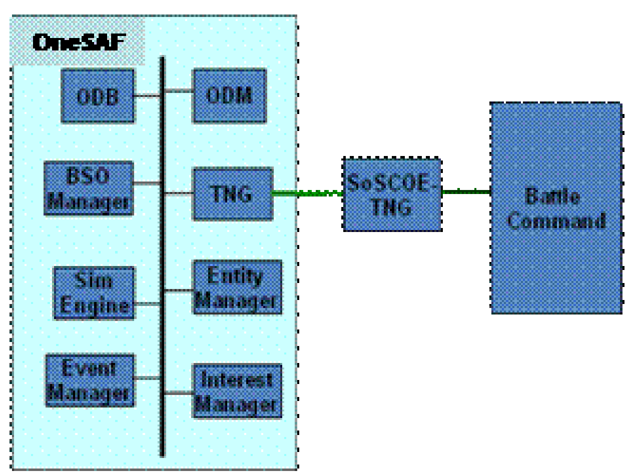

Figure 2 TNG Components

Another problem the demonstration team had to resolve was how to complete a fire mission. The BCME component, shown in Figure 1, expects its software to be running on the effector platform. One solution was to install this component on a surrogate effector computer. However, one scenario had 41 effectors (shooters) and would have required 41 separate computers. Hence the demonstration team developed the Mock FEC Effector. This component was a SOSCOE application and interfaced with the SOSCOE TNG. The Mock FEC Effector initiated a new process for each requested effector. This process mimicked the BCME interface and passed fire mission requests to the SOSCOE TNG where they were sent to OneSAF for execution. As OneSAF conducted a fire mission, status messages (e.g. in progress, rounds complete) were sent through the TNG and the Mock FEC Effector to battle command which were displayed on the Warfighter Machine Interface (WMI). Once OneSAF completed the fire mission, an end of mission was sent back to battle command through the TNG and the Mock FEC Effector, thus completing the end-to-end thread.

Data Collection

Simply executing and observing interaction occurring on the OneSAF Personal View Display (PVD) and WMI screens was not sufficient to prove the RBD services in the battle command software were working properly. The demonstration team had to provide evidence that the correct decision was being made by battle command. For example, if a fire mission was denied because of a fratricide conflict there needed to be evidence that there was a blue BSO in the effects hazard area for that particular fire mission. In addition, the program required the simulation environment be accredited for this demonstration so the team had to provide evidence that OneSAF and the TNG were operating as expected. As shown in Figure 1, the demonstration team utilized several tools to accomplish this task that ranged from battle command log files to an after action review tool (Pioneer) and a real-time exercise monitoring tool, Intelligent Exercise Monitor (IEM).

Pioneer is an after action review tool that was developed to work with any simulation with only minor modifications required. Pioneer is capable of reducing large amounts of data and visually displaying that data to the user. The demonstration team expanded Pioneer to process battle command's large log files. Figure 3 is an example of a Pioneer plot that was used to indicate when a UAV began to violate an Airspace Control Measure (ACM).

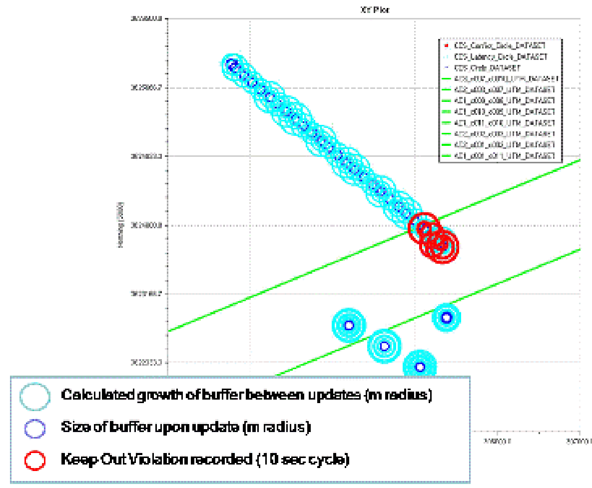

Figure 3 Pioneer Plot

In Figure 3 the green lines are drawn from the ACM data that was written out in one of the battle command log files. In this same log file was data that corresponded to the UAV location and the size of the dynamic safety buffer around it. This data is visually depicted by the dark and light blue circles. The red circles in the diagram depict when battle command detected a conflict between the UAV and the ACM. Attempting to examine this data in an Excel spread sheet would be impossible because the log file contains over two million records. However, by visualizing the data with Pioneer the team could quickly show that battle command was working properly.

In order to avoid costly false record runs, to conduct VV&A, and to provide additional evidence that battle command met the assessment objectives, the team needed to have detailed visibility of each test case as it was executing. IEM was developed to monitor simulations during execution to ensure that demonstration requirements were being satisfied. As with the Pioneer tool, the demonstration team expanded the IEM capability to monitor battle command events. This was accomplished by adding a SOSCOE interface to IEM which allowed a pub/sub connection to the platform updates internal to battle command services as well as a client/server connection to the Fire Mission/ Fire Mission Response interactions. This allowed the team to monitor all data being passed back and forth between battle command and OneSAF in real-time.

Another area the Pioneer and IEM tools proved to be helpful was in the development cycle of the demonstration. Weekly integration runs were conducted early in the development cycle which allowed the development team to identify issues in both the simulation environment and in the battle command software. For example, during an early integration test the WMI display was only displaying 15 blue BSOs upon startup instead of 161. Using the IEM tool the team quickly realized there was a problem with the OneSAF TNG component and was able to quickly resolve the issue. During another integration test the team used Pioneer to plot the BSO safety buffer size over time. This plot revealed that the safety buffer for a given BSO did not always get reset causing false conflicts. The responsible One Team Partner (OTP) was able to determine that it was a thread issue simply by examining the anomalies on the plot.

VERIFICATION, VALIDATION & ACCREDITATON

The FCS program decided to require all critical technology demonstrations be accredited for their intended use. For the RBD demonstration this meant satisfying nine acceptability criteria that were established by the FCS Modeling and Simulation Office (MSO).

Acceptability Criteria (AC)
AC1 Terrain: *The M&S relevant environment must provide simulated terrain and environment representations that support the technology.*

To satisfy AC1, test measurements were taken of terrain in OneSAF and in the battle command software to ensure location reporting was consistent. However, the demonstration did not require any terrain data to be passed from the simulation to the RBD services.

AC2 Operational Consistency/Configuration Management: *The relevant environment must ensure operational consistency regarding its functional use and capability, and physical characteristics, as described in AR 5-11, Chapter 6, Configuration Management, which includes, but not limited to, purpose, assumptions, limitations etc. that must be documented and properly maintained.*

AMRDEC used StarTeam & Caliber RM to manage all demonstration artifacts. This provided the team the capability to demonstrate the traceability from the assessment objective to the test case procedures indicating completeness and consistency. In addition, all anomaly reports were managed by StarTeam which allowed the team to trace why any change was made to all required demonstration artifacts.

AC3 Simulated Platforms: *The simulated entities for Blue and Red forces must be FCS and non-FCS entities available in OneSAF 2.1 and approved by the demonstration sponsor.*

The RBD design lead for the demonstration participated in a scenario review for each test case. Caliber RM was used to document the approval for each test case which also indicated the scenario was approved by the demonstration sponsor. In addition, the team requested each scenario be reviewed by the TRADOC War Gaming Scenario Working Group which also approved the scenarios, indicating that they were operationally relevant.

AC4 Data Inputs: *Data used in OneSAF 2.1 or other government furnished equipment (GFX) to support the demo must be verified, validated, and certified (VV&C) for intended use, as described in AR 5-11, and the demo plan.*
The demonstration team conducted a series of dry runs where the RBD design lead thoroughly reviewed and certified all the OneSAF data that was to be used in the demonstration. No other data was used for the demonstration.

AC5 Network: *The network shall operate within plus/minus one (1) second of real-time with simulated entities generated by individual simulations and the relevant environment.*

The demonstration team elicited assistance from the lab's network administrators who used several Cisco utilities to measure the performance of the network during an integration test. The results of the test proved the network was operating well within this requirement.

AC6 Interoperation/Integration: *The M&S relevant environment must be able to communicate/interoperate with Unit Under Test (UUT) systems to send, receive, and acknowledge fire missions, responses to fire missions, Battle Space Object (BSO) inputs/updates and logistics messages related to fire missions.*

As previously mentioned, IEM was used to assist with the VV&A effort. For this particular AC, IEM measured and displayed each parameter listed in the AC which allowed the VV&A to conduct output validation real-time. Log files from OneSAF, IEM and battle command were also compared for consistency.

AC7 Situational Understanding: *The Demonstration network must provide evidence that Situational Understanding/ Situational Awareness SU/SA of simulated entities (e.g., air and ground vehicles, threats, etc.) was sent to the Unit Under Test (UUT). SA/SU will consist of position and identification (Blue and Red) for all simulated entities. Appropriate messages must be transmitted and received among the simulated entities between the M&S relevant* *environment and the UUT.*

This AC was satisfied in the same manner as AC 6.

AC8 Communications: *Components supporting the RBD TRL-6 Demonstration must be able to communicate among themselves using the appropriate protocols confirmed by demonstration results.*

This AC was satisfied in the same manner as AC 6.

AC9 Output data: *The RBD TRL-6 Demonstration M&S relevant environment output data must be properly formatted, adequate and credible to support the assessment objectives and analysis of the technology readiness level.*

To satisfy this criterion, the demonstration team organized data according to the guidelines specified in Table 2.

Level	Description	Possible forms	Example of content	Disposition
Level 1 “Raw Data”	Data in their original form. Results of field trials just as recorded.	Complete data collection sheets, exposed camera film, voice recording tapes, original instrumentation magnetic tape or printouts, original videotapes, completed questionnaires, and/ or interview notes.	1. All reported target presentations and detections. 2. Clock times of all events. 3. Azimuth and vertical angle from each flash base for each flash. 4. Recording tapes of interviews accumulated during trials for processing.	Usually discarded after use. Not published.
Level 2 “Reduced Data”	Data taken from the raw form and consolidated. Invalid or unnecessary data points deleted. Trials declared “No Test” deleted.	Confirmed and corrected data collection sheets, film with extraneous footage deleted, corrected tapes or printouts, and original raw data with “No Test” events marked out.	1. Record of all valid detections. 2. Start and stop times of all applicable events. 3. Computed impact points of each round flashed. 4. Confirmed interview records.	Produced during processing. Usually discarded after use. Not published.
Level 3 “Ordered Data”	Data that have been checked for accuracy and arranged in convenient order for handling. Operations limited to counting and elementary arithmetic.	Spread sheets, tables, typed lists, ordered and labeled printouts, purified and ordered tape, edited film, and/or edited magnetic tapes.	1. Counts of detections arranged in sets showing conditions under which detections occurred. 2. Elapsed times by type of event. 3. Impact points of rounds by condition under which fired. 4. Interview comments categorized by type.	Not usually published but made available to analysts. Usually stored in institutional databanks. All or part may be published as supplements to the test report.
Level 4 “Findings” or “Summary Statistics”	Data that have been summarized by elementary mathematical operations. Operations limited to descriptive summaries without judgments or inferences. Does not go beyond what was observed in the test.	Tables or graphs showing totals, means, medians, modes, maximums, minimums, quartiles, deciles, percentiles, curves, or standard deviations. Qualitative data in the form of lists, histograms, counts by type, or summary statements.	1. Percentage of presentations detected. 2. Mean elapsed times. 3. Calculated probable errors about the centers of impact. 4. Bar graphs showing relative frequency of each category of comment.	Published as the basic factual findings of the test.

Table 2 Data Organization

LESSONS LEARNED

There were several lessons learned regarding the battle command software, all of which have been incorporated into future builds of FCS BCS. In addition, there were a few lessons learned that pertain specifically to the use of M&S in TRL evaluations which are discussed below.

Configuration Management

Although the team adhered to strict CM practices, configuration management was still an issue because each stakeholder in the demonstration (FCS LSI, OTPs, and AMRDEC) used their own CM tools and methodology. Thus every demonstration anomaly report had to be manually duplicated in each CM tool. To ensure consistency across each CM tool the demonstration team conducted time consuming teleconferences twice a day with the LSI and the OTPs. Future events would benefit tremendously by standardizing on a single tool and process for configuration management.

Data Collection

Data collection for the simulation environment was relatively straight forward compared to the RBD services. Although every RBD service had either a log file or a test GUI interface, they were not designed to provide enough evidence to determine if the correct decision was made. They simply recorded that an event occurred and the result of the event. As a result, the OTPs had to make many modifications to the service logging statements during the integration events.

Future acquisition programs should consider what data must be provided in order to prove software maturity at the very beginning of the program and should design robust data collection into the software. This event proved that adding necessary data collection routines as an afterthought dramatically reduces the likelihood of completing the demonstration on time and within budget.

Interoperability & Reuse

Interoperability and reuse technologies have continued to mature over the past decade in the M&S community, and many simulations have support for multiple technologies such as DIS and HLA. However, these technologies limit themselves to M&S, resulting in a gap that must be overcome when the M&S community attempts to interact with real tactical systems. In the past this problem has been solved by developing some sort of gateway that will translate the DIS or HLA messages into actual tactical messages, thereby increasing the development cost and schedule. As demonstrated in this event, it is feasible and cost effective to move away from traditional M&S technologies and to create tactical messages directly from the simulation.

CONCLUSIONS

In December 2008, the DoD issued new procedures for defense acquisition programs [DoD Instruction 5000.02, December 2008]. These new procedures will increase the dependencies and demands on modeling and simulations. For example, prior to a material decision (Milestone A) an Initial Capability Document (ICD) must be developed. The ICD describes the operational goals and indicates that multiple concepts have been explored and that a material solution is the most appropriate means for obtaining the operational goals. Modeling and simulation will most likely be the most cost effective means for examining all the concepts being considered. Simulations such as OneSAF have matured to the point to where they are poised to meet the demands of a Milestone A decision.
However, as an acquisition program progresses along its evolutionary path, the evaluation of that program's maturity becomes increasingly complex. Thus M&S must become an integral component of the acquisition program, and the simulations must be able to seamlessly traverse the simulation and operational/tactical domains without the use of complex and costly gateways. The concept of a system of systems common operating environment such as SOSCOE offers this possibility. Developing both tactical and simulation systems using a common operating environment would reduce the need for simulation specific protocols and would allow simulations to provide an operationally relevant environment that could be used continuously throughout a program's lifecycle to evaluate and provide feedback to the acquisition program under development.

REFERENCES

DoD Technology Readiness Assessment (TRA) Deskbook, May 2005

DODI 5000.02 December 2008