1.1 Constructive Engineering of Simulations

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Joint experimentation that investigates sensor optimization, re-tasking and management has far reaching implications for Department of Defense, interagency and multinational partners. An adaption of traditional human in the loop (HITL) Modeling and Simulation (M&S) was one approach used to generate the findings necessary to derive and support these implications. Here an entity-based simulation was re- engineered to run on USJFCOM's High Performance Computer (HPC). The HPC was used to support the vast number of constructive runs necessary to produce statistically significant data in a timely manner. Then from the resulting sensitivity analyses, event designers blended the necessary visualization and decision making components into a synthetic environment for the HITL simulations trials. These trials focused on areas where human decision making had the greatest impact on the sensor investigations. Thus, this paper discusses how re-engineering existing M&S for constructive applications can positively influence the design of an associated HITL experiment.

1.0 INTRODUCTION

United States Joint Forces Command (USJFCOM) Joint Concept Development and Experimentation Directorate (JCD&E) develops innovative joint concepts and capabilities providing experimentally proven solutions to the most pressing problems facing the joint force. JCD&E mitigates risk for DoD through rigorous evaluation of alternatives and through the development, testing and validation of joint concepts focused on specific problems identified in the Joint Operating Environment or gaps in doctrine. Joint experimentation is complementary with other elements of DoD research, development, testing and evaluation offices and applies similar methods to those used in technology test & evaluation and field demonstration. J9 leads and coordinates JCD&E for DoD through an enterprise approach, applying structured, disciplined and transparent processes that maximize effectiveness and efficiency (JCD&E, 2010).

1.1 Useful Definitions & Concepts

A model is a description of the underlying methodology used to conduct an investigation, and a simulation is the implementation of that model that can occur via automation (Akst, 2010). Further, Akst wrote that simulations should not be built before developing the underlying models, and that the first step in successful model development must be to understand the intended use of both the models and the simulations (M&S).

1.2 Intended Use of the M&S

One JCD&E sponsored experiment was the Joint Integrated Persistent Surveillance (JIPS) project. This experiment included constructive simulation (CS) and Human in the Loop (HITL) activities which were instantiated on USJFCOM's High Performance Computer (HPC). Based on the analysts' developed metrics, M&S generated the environments necessary to allow analysts to capture data associated with those metrics. First, metrics were generated with the G2 process model (Snyder, 2010). These metrics represented the human decision making process, where model outputs were used to initialize the simulation, so that human interactions were not required during execution of the CS runs. Then for the HITL trials, solutions were investigated with the introduction of humans, as an alternative representation with complementing strengths and

weaknesses to the CS approach, which assisted in validating the modeled representations of the decision-making process. The CS provided a means to conduct a high number of trials not only for increased precision in the statistical output, but also to manipulate an increased number of solution set variables. Within the HITL, the number of trials was significantly decreased; however, the advantage was in the interaction of real people with the solutions. Insights that the analysts gained from the CS runs were used to assist event designers in determining the necessary M&S configurations for the associated JIPS HITL trials. Results from the HITL were used to assist designers in determining the setup of additional CS runs in keeping with a model-wargame-model (W-M-W) paradigm (Kass, 2006).

1.3 Event Design

The JIPS HITL provided experimental evidence to assist in determining the effectiveness and efficiencies of solutions against current day and futuristic baselines. Prior to the HITL runs, thousands of faster than real time CS runs were executed to examine the impact of the various solutions.

Then during the HITL trials, solutions were carried forward with the introduction of a human decision-making component to further examine the solutions with the introduction of command, control, communication, computer, and intelligence (C4I) systems.

1.3.1 Experimentation Audience

Figure 1 illustrates the four echelons of command that were emulated during the HITL. These echelons were: national to include combatant command (COCOM), joint task force (JTF), division (DIV) and regimental combat team (RCT) with associated tactical elements such as battalion and companies. In turn, parts of seven levels of Command and Control (C2) were emulated by these four echelons. The blue shaded area represented the experiment audience, and the pink shaded area represented the control cell with role players. The control personnel, called the White Cell (WC), ensured that the simulation rendering of the enemy activities, friendly assets and neutral ground activities were sufficient to stimulate the participants' behavior. The analysts observed these behaviors and gathered data from the
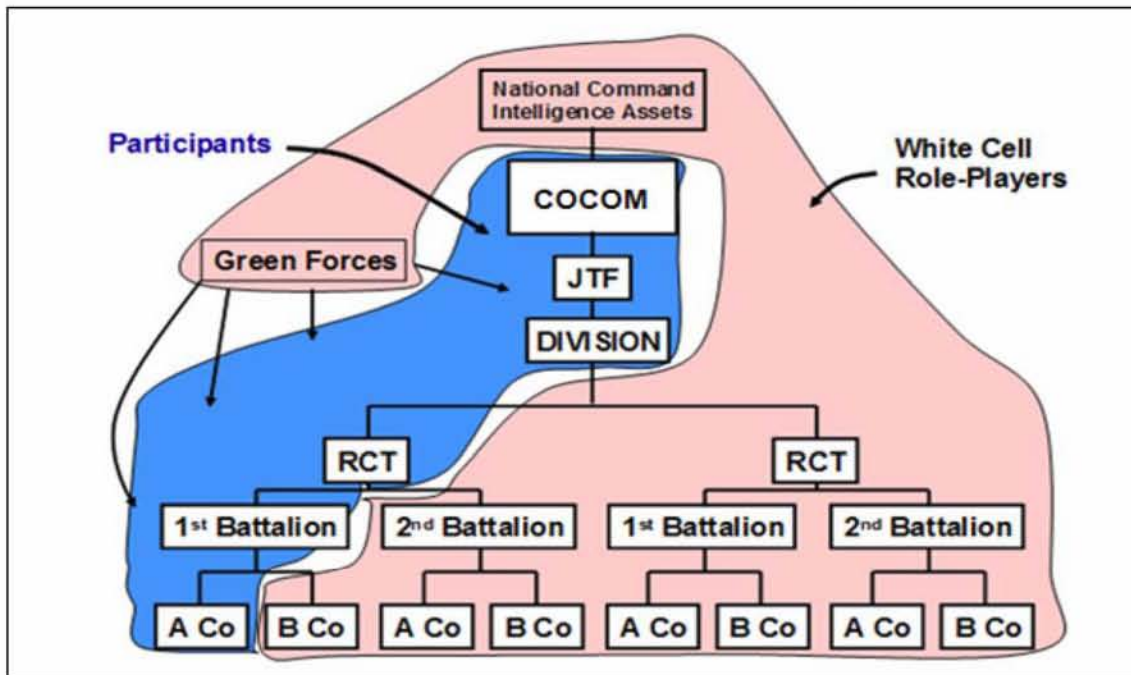

Figure 1. Separation of participants and simulation

simulation to develop their findings in keeping with the Data Collection and Analysis Plan (DCAP). M&S operators resided in the WC to assist in masking the M&S activities from the participants in order to enhance the realism of the experiment.

1.3.2 Communications

In addition to providing data in support of analysis, the simulation was also the data source for the integrated C4I systems which were used by experiment participants to carry out their duties. The M&S was used to facilitate sensor asset re-taskings, full motion video (FMV) taskings and system status reporting. Internet Relay Chat (mRIC) was the primary mode of communication among M&S operators, analysts, collection managers, targeteers and sensor asset managers at all echelons. Command and Control Personal Computer (C2PC) and Command Post of the Future (CPOF) presented participants with a shared representation of battle space entities as generated by the simulation. Email was the secondary communication channel that was available at all four echelons to send and receive lengthy textual reports such as formatted intelligence reports. Additionally, voice over IP (VOIP) provided a digital voice communication capability at all JIPS HITL workstations. These HITL workstations emulated those of real world C2 centers.

2.0 BODY

Supporting the HITL were federation M&S components that stimulated the C4I tools. These stimuli evoked behaviors from the participants which were of interest to the analysts.

2.1 Federation Components

There were six primary M&S components used in the HITL to generate situational awareness (SA) for the participants, and five of these components directly drove the Common Operating Picture (COP). First, Joint Semi-Automated Forces (JSAF) was the entity level simulation that represented the opposing entities. These entities were controlled by human operators and the

JSAF automated behaviors. Second, CultureSim, a scalable entity level federate tightly coupled with JSAF that was formerly known as ClutterSim, represented the neutral populace reflected within the urban battlespace (Speicher, 2004). Third, Simulation of the Locations and Attack of Mobile Enemy Missiles (SLAMEM) was the entity level simulation used to represent sensors, sensor platforms, fusion, and tracking. Fourth, a redesigned Track Database (TrackDB) federate enabled direct communications from JSAF to the C4I components. This modified TrackDB federate replaced the need for a separate C4I gateway to feed the Global Command Control System – Joint (GCCS-J) server. C2PC and CPOF clients pulled data from GCCS-J. Fifth was the three dimensional JSAF viewer (JStealth), which produced effects that closely resembled those from emulated platforms generating FMV feeds. Finally, an experimentation & event tool suit (EETS) component, the Event Generator (EventGen), facilitated the injection of master scenario event list (MSEL) items. The EventGen injects supplemented the perceived behavior of the simulation entities. These injects were represented as emails that did not directly influence the COP, but did provide amplifying context and intent to further influence the players' reaction to the M&S stimulation of the COP.

2.2 C4I and M&S Architectures

M&S operational requirements for the JIPS HITL were broken out into the five areas. In turn, four technical spirals and one operational test were used to ensure that these five areas were sufficient to successfully accomplish the experiment from a technical standpoint (JIPS, 2010). These tests were conducted to ensure that surveillance and network architectures, simulation and communication components, plus the control procedures were sufficient to meet event objectives. Figure 2 depicts how the M&S components interfaced with the COP and the FMV view generators to stimulate the participants. Not all message

traffic was processed through the TrackDB. Over-the-Horizon (OTH) Targeting Gold

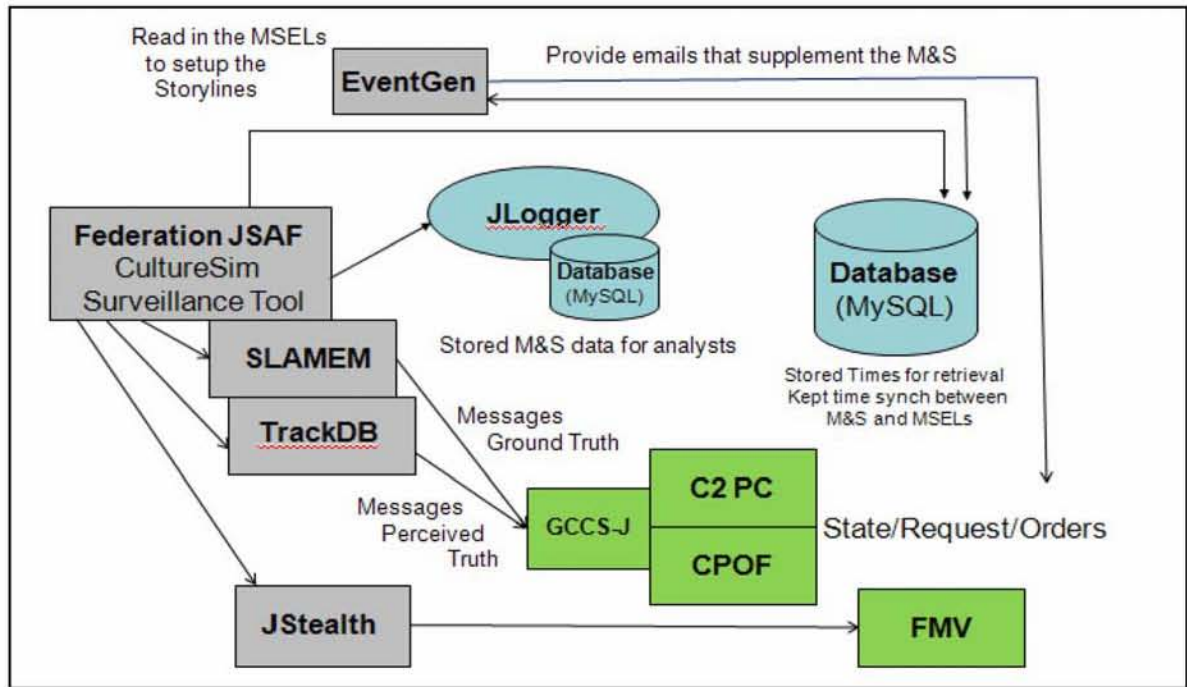to obscure the enemy activities that were represented in JSAF. MSEL items

Figure 2. Simulation and C4I Architectures

(OTG) messages passed initial detections directly from SLAMEM to the GCCS-J server. The perceived current track states were sent via the TrackDB. Objects and interactions from SLAMEM and the TrackDB were pulled from the Federation and placed into a MySQL repository for later analytical use. In some cases, SLAMEM data were captured in SLAMEM logs, and other Federation traffic was pulled via a separate application called JLogger. TrackDB was enhanced for this event to send track data directly to the GCCS system, removing the need for a separate C4I gateway. The JSAF Surveillance Tool was the mechanism used to allow re-tasking of sensor assets.

2.2.1 Re-tasking Sensors Assets
During the HITL, participants tasked sensor assets to collect information on perceived enemy activities as instantiated in JSAF. Closely coupled with JSAF was the CultureSim federate which generated thousands of neutral entities which served

established the initial taskings for the sensor assets that were represented in SLAMEM. Once re-tasking requests were approved and authorized, HITL participants required the capability to influence airborne sensor assets to change the location of interest view, the assigned sensor on location, and/or fly a new route to meet a new or modified collection requirement. From an M&S perspective, blue sensor assets, represented in SLAMEM, had to be capable of changing their station, their surveillance area, or their sensor modes as directed by HITL participants.

2.2.2 Observe FMV
From an M&S perspective, FMV was simulated by attaching JStealth to simulated sensor assets that were represented in SLAMEM. The simulated FMV feeds, which were visualized through JStealth, were fed to a video server capable of streaming the video over the network to participants' C4I displays. HITL participants requested FMV feeds via the WC. Working within the WC,

the M&S operators changed the FMV views per the participants' requests.

2.2.3 Inject Scenario/MSEL Events
The experiment executed a scenario with multiple storylines to provide target activity for persistent and non-persistent surveillance. Detailed events from each storyline were compiled into a single chronologically ordered event list known as the MSEL, which was executed at the discretion of the white cell. The WC controlled MSEL inject flow via EventGen. The control group also had the responsibility to add to or delete from the MSEL injects to ensure the experiment objectives were accomplished.

2.2.4 Situational Awareness
Situational awareness (SA), as applied to the JIPS HITL, was the capability to extract meaningful activities and patterns from the battlespace picture and to share this awareness across the network with appropriate participants (Hayes, 2006). The COP provided the cognitive understanding or interpretation of the JIPS battlespace. The JIPS battlespace was composed of the following four SA components (JIPS, 2010):

- Blue Force SA component – a complete picture of all Blue force entities including their identification and position. Blue force sensor entities were modeled in SLAMEM.
- Red Force SA component – a complete picture of all Red (hostile) force entities including their identification and position. Red force entities were modeled in JSAF.
- Green Force SA component – a complete picture of all civilian units/entities including their position and (optional) identification information. The Green component was modeled in JSAF, which included cultural activities, i.e., people, vehicles, and landmarks.
- Sensor SA component – a picture of the perceived entities sensed in the

battlespace and reported by Blue force sensor systems. Blue force sensor reports were produced by SLAMEM.

2.2.5 M&S Data Collection
The JIPS HITL exercised the innate distributed collection mechanisms of the tools and logged all federation simulation traffic. The After Action Review (AAR) was supported by various means of consolidating the data from the HPC, data fusion techniques, and data reduction into user friendly formats as specified by the JIPS analysts.

3.0 DISCUSSION

3.1 Synthetic HITL Environment
The JIPS HITL federation was composed of simulations selected to best meet the multi-echelon command structure of joint persistent surveillance operations. The goal of the JIPS technical and operational test program was to mitigate the risk inherent in the use of disparate simulation and SA components by investigating and evaluating the functionality and interfaces of the components within the framework of the event objectives. For the JIPS experiment, persistent surveillance was defined as a collection strategy that emphasizes the ability of collection systems to linger on demand in a particular location to detect, locate, characterize, identify, track, target and assess in real or near real time (HQDA, 2010).

3.2 M&S Architecture
Various optimization techniques where employed to take advantage of the HPC architecture and address experimentation objectives.

3.2.1 Entity Count
In order to reach the JIPS HITL 100,000 entity count target, several federation routers and CultureSim nodes where configured to take advantage of the M&S Data Distribution Management (DDM) protocol. This approach reduced the

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number of interactions within the federation to a degree sufficient to support pockets of densely populated urban terrain areas.

3.2.2 Gateway Redesign
Given the probability that sensor collection plans would include fly-over of these dense populations, it was necessary to optimize the C4I Gateway to support the simulation-to-C4I translation of large numbers of perceived tracks. This was resolved by, 1) redesigning the TrackDB federate to replace the C4I Gateway, effectively removing the less efficient runtime database access requirement and, 2) bundling and distributing consolidated sensor reports as opposed to individual tracks.

3.2.3 Data Collection
During runtime, a distributed data collection approach was used. Collection was localized at each simulation/HPC node reducing the runtime data throughput requirement. After each HITL run, the data was off-loaded from the HPC onto a

the nodal scheme: yellow blocks represented JStealth nodes, green blocks represented CultureSim nodes, purple blocks represented SLAMEM nodes, grey represented router nodes, red blocks represented JSAF nodes, and the white blocks represented the simulation that held the track histories. The node reference numbers within the blocks corresponded to 256 nodes that were mapped to a particular application. Blocks without node references represented stand alone components. Due to the heavy data traffic on the HPC, several nodes were dedicated to routing the traffic. Additionally, a majority of the HITL nodes were dedicated to instantiating JStealth and CultureSim due to their high computational demands.

3.3 Operational M&S Requirements
The approach to operational testing began with identifying a set of operational requirements having functional dependencies on the M&S. In turn, the CS runs were used to assist the setup of the
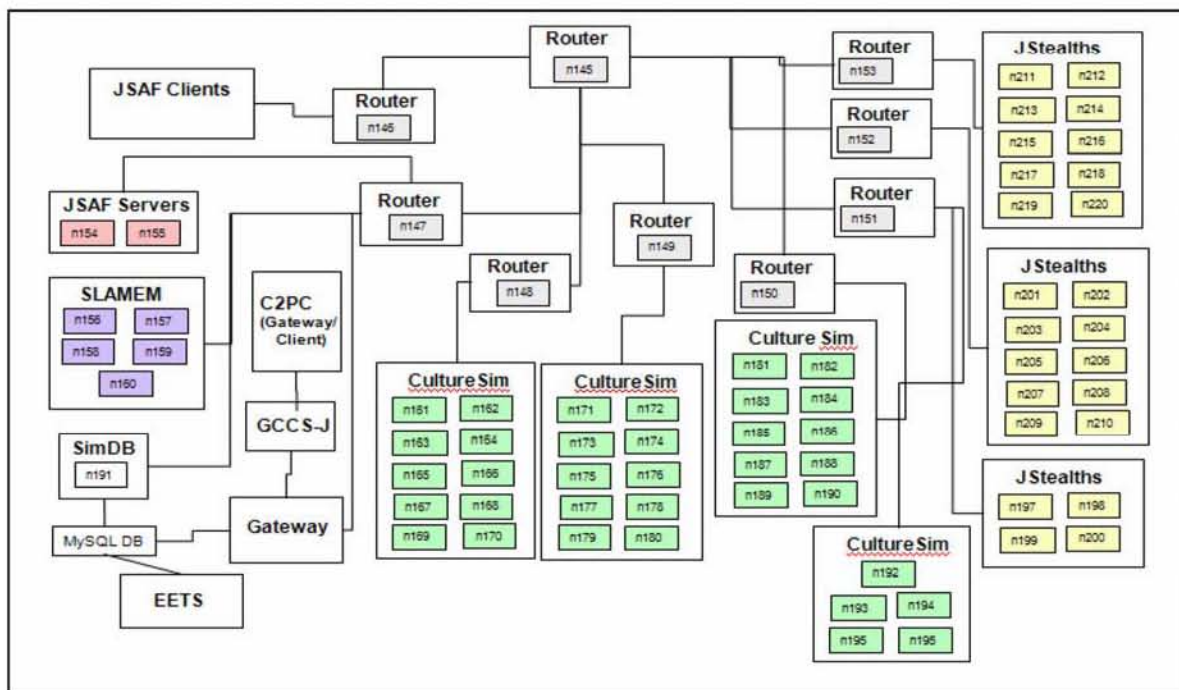

Figure 3. HPC Network Connectivity Map

centralized repository for analysis. Colors used in figure 3 highlight the complexity of

HITL simulation trials. The primary difference between the CS and HITL runs

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was the human interactions by the participants. Observations made of these actions were used to validate the human decision making models. Other differences were associated with the addition of M&S and C4I to stimulate components that provided credible visualization and decision support aids to assist the participants in making decisions.

3.3.1 Constructive Inputs
From the CS, insights into how the FMV views should be synchronized with the MSEL injects resulted in multiple screen views for the participants. The information gathering and fusion processes, associated with the FMV views, were implicitly performed during the CS runs. By using the same sensor simulation for both the HITL and CS runs, this commonality assisted event designers in establishing traceability between the CS and HITL results.

3.3.2 Scenarios
Traceability was reinforced by using the MSEL descriptions of the scenario's storylines to develop the synthetic representations of the people, enemy forces and the necessary landmarks to stimulate the participants such that they would re-task assets as SA dictated. In other words, the JIPS event designers used the implicitly represented actions in the CS runs to determine the appropriate actions that the human participants would explicitly need to execute during the HITL runs. Simulation time was maintained in a MySQL database (Figure 2). The EventGen tool kept the MSELs synchronized with the simulations by reading and writing to this database.

3.3.3 Refining Models
Per the M-W-M paradigm, the first set of G2 models were based on expert judgment to develop time estimates that predicted the participants' performance during execution of each solution in the HITL. Next, HITL observations were used to update the experts' time estimates, which led to refining the G2 models for the second series of model runs.

4.0 CONCLUSIONS
The JIPS HITL was conducted to provide experimental evidence on the effectiveness and efficiencies of potential solutions to the persistent surveillance problem. The implementation of the HITL experiment on the USJFCOM HPC was necessary to fully implement the M-W-M paradigm. With the ability to rapidly refine the G2 models based on metrics derived from the HITL, the HPC made the re-running of the CS feasible within the project's time constraints. Thus, event designers used the HPC to achieve a closer coupling between the modeling and wargaming trials than what was previously possible in other JCD&E M&S supported activities. This coupling came from using the output data of the HITL to further refine the G2 models used for a second set of CS runs.

4.1 Constructive Engineering
Based on the results of using a version of SLAMEM in a constructive simulation mode, lessons were learned which influenced how best to custom build a JCD&E experiment with M&S and C4I components. This environment was sufficient to provide participants with the SA necessary to make meaningful decisions in line with the desires of the analysts. Observation tools and surveys were used daily, and the simulation generated metrics provided context which allowed traceability back to the DCAP. The use of common MSELs, between the CS and HITL trials, became an important factor for facilitating traceability as well as saving the time necessary to create a different set of MSELs.

4.2 Resources
Without the M&S environment created by the USJFCOM HPC, dozens of additional stand alone servers and operators would have been needed to correlate the answers and findings. Additionally, from the resulting sensitivity analyses event designers were able to select the sufficient type of visualization and decision making components to create the necessary HITL environment. It was the application of the

USJFCOM HPC resource that allowed for the focused and timely manipulation of simulation data, routing of data traffic, and stimulation of the C4I systems that provided the human decision makers a credible environment for JIPS investigations. This manipulation of data was sufficient to provoke the participants to take actions that were of interest to the analysts.

4.3 Optimization Techniques

Intelligently exploiting the M&S DDM protocol on the HPC led to the reduction of inter-node simulation interactions thus reducing network traffic and unnecessary message processing. Additionally, localizing the collection of data at each simulation/HPC node reduced the runtime data throughput requirement. After each HITL run, the data was off-loaded from the HPC onto a centralized repository for analysis. However, it was the redesign of the TrackDB federate and bundling of sensor reports that proved to provide the most benefit to the participants. This was because the redesign and reconfiguration reduced C4I track latencies, and contributed most to an environment that dispelled disbelief in a constructively engineered world.

5.0 REFERENCES

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6.0 ACKNOWLEDGMENTS