

Pointing the Way with Constructive Simulations

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ABSTRACT

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. Operationally relevant solutions are rapidly delivered to support current operations and drive changes to better enable the future joint force. JCD&E provides thought leadership and collaborative environments to generate innovative ideas with a range of interagency, multinational, academic and private sector partners.

One JCD&E enterprise sponsored experiment involves the investigation of sensor optimization, re-tasking and management. For this experiment, Modeling and Simulation (M&S) was used to support development of the necessary analytical framework. Here, M&S was used to produce objective and quantitative data which supported the analysts' insights. For this particular experiment, running M&S in a Constructive Simulation (CS) mode was deemed necessary to bound the problem domain. Process modeling was used to determine the variables that represented the human decision making processes under investigation. Then these variables were used during the faster than real-time CS runs that were executed on USJFCOM's High Performance Computer (HPC). The simulation used the process model to validate the dependent variables used in the CS runs. The HPC was used to support the vast number of CS runs necessary to produce statistically significant data to support the analytical findings.

Hence, this paper discusses how the JCD&E enterprise identified and designed a project that used process modeling and CS runs. Discussions include lessons learned on how modeling can produce validated data to support CS runs. Finally, this paper concludes with a discussion as to how the constructively produced data, from the process modeling and CS runs, assisted in refining the follow-on Human In The Loop trials.

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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).

The JCD&E uses collaborative environments to generate innovative ideas with a range of interagency, multinational, academic and private sector partners. These partners nominate challenges that are distilled into an experimental form via a deliberate selection and prioritization process. This process establishes a logic trail between the problem statement and the desired outcomes. The causality between the problem being investigated and experimental findings are captured in requirement traceability matrices. When appropriately applied, Modeling and Simulation (M&S) can assist in gathering the metrics specified in supporting Data Collection and Analysis Plans (DCAPs) to support the experiment's findings. Additionally, using M&S to support experimental findings can improve analytical rigor, which is the application of precise and exacting standards in the examination of a question carried out under controlled conditions to better understand and draw conclusions in order to discover an unknown effect, to test a hypothesis, or

demonstrate a known fact, and usually based on careful consideration or investigation (MORS 2006). Further, M&S data produced during verification and validation testing may be used to make the findings more credible to partners when mapped to the requirement traceability matrices. Hence, M&S can generate data to support the analysts' developed metrics that establish some level of control and manipulate factors of interest in order to establish or track cause and effect (Stenbit 2002).

To support requirements traceability, objective and quantitative data is sought because experiments by their nature need to be repeatable (Stenbit, 2002). Several types of M&S environments can generate useful repeatable data. These virtual environments represent the capabilities, limitations and constraints that govern the behavior of objects represented in the virtual battle-space. Constructive simulations (CS) are a mainstay of warfighting experimentation that military analytical agencies employ that allow repeatable replay of the same battlefield scenarios using the identical battlefield geometry or conditions, while systematically varying parameters (Kass, 2006). In turn, the JCD&E employs M&S to generate constructive environments that support collaboration and provide a means to enhance the analytical rigor sufficient to substantiate findings derived from experiments. Thus, M&S enhances analytical rigor by allowing analysts the ability to control and monitor independent and dependent variables in a repeatable manner.

CONCEPTS AND DEFINITIONS

One recent JCD&E joint experiment investigated methods to better manage, integrate and optimize sensor collection systems. Here, the M&S's intended use was to assist in comparing solutions that may improve the warfighter's ability to conduct persistent surveillance (PS) over many desired activities under varying weather conditions. For the purpose of this paper, PS is

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). This JCD&E sponsored experiment was called Joint Integrated Persistent Surveillance (JIPS).

Experiment Planning and Design

Early in the JIPS event design phase, planners recognized that an innovative approach was needed to support the ability to detect and isolate changes that proposed solutions would have on the virtually represented intelligence collection system of systems. Having an ability to detect and isolate changes made in the resultant data, due to implementing solutions, greatly assisted in establishing the validity of the experiment's design. Validity is defined as the measures, metrics, and indicators employed that actually measure what the experimentation team is trying to measure (Stenbit, 2002). In turn, a model-wargame-model (M-W-M) paradigm approach was adopted to generate and conduct timely analyses of the anticipated huge volumes of data necessary to support the JIPS findings. The M-W-M paradigm combined constructive experiments and human-in-the-loop (HITL) virtual wargames to make up for the validity deficiencies by either when executed in isolation (Kass, 2006). For JIPS, modeling was used to represent the human decision making processes, and a simulation represented the environments where the human decisions were implemented to determine metrics of interest as specified in the DCAP. A simulation was used to support the wargame portion of the M-W-M paradigm by defining the battlefield geometry among the ground activities, terrain and sensors that were employed to access the different solutions represented in a process model.

High Performance Computer

In support of JIPS requirements, an entity-based sensor simulation was re-engineered to run on USJFCOM's High Performance Computer (HPC) in a Faster-Than-Real-Time (FTRT) CS mode. The CS results were used to statistically bound the problem domain and assist the analysts in determining how to maximize human involvement in follow-on human in the loop (HITL) M&S supported activities. In this regard, a process modeling technique was used to determine variables that accounted for the

human decision making process as the FTRT trials were executed on USJFCOM's HPC. JIPS M&S planners used a process model to expose the processes for generating dependent variables to subject matter experts. These experts validated the processes which generated key variables which later served as simulation inputs. Not only was the HPC used to support the vast number of CS runs necessary to produce statistically significant data without human involvement, but scripts were written that periodically re-ran the data through the HPC. This second pass served to manipulate the raw data into formats that the analysts could more easily analyze.

Then from the ensuing sensitivity analyses, event designers blended the necessary visualization and decision making components into a synthetic environment for the HITL simulations trials, which occurred as separate activities from the CS runs. For the HITL activities, the same sensor simulation and scenarios were executed in a real time federation to assist in correlating the CS and HITL results. While some energy was expended to engineer the process model to run on the HPC, it was deemed sufficient to only read the human decision making variables into the CS. Thus, this paper focuses on how the re-engineering of an entity-based simulation for a constructive applications could be coupled with process modeling techniques to positively influence the design of an associated HITL experiment. Understanding that the detailed discussion of the HITL JIPS trials was outside the scope of this paper, it is important to recognize that there was a conscious decision made to couple together the CS and HITL activities. While this coupling will not be addressed in detail, the HITL activities will be addressed again in the lessons learned portion of this paper.

HPC ENVIRONMENT

USJFCOM partnered with leading Industry experts to develop a 256 node HPC capability in Suffolk, Virginia. However, only 150 nodes of USJFCOM's 256 node, 1024-core HPC Linux cluster were used due to the classified nature of the JIPS CS runs. Each node was controlled and monitored by a custom simulation daemon called *simd*. The client *simd* ran on each node and received control statements from the HPC management server. Each of the 150 nodes ran in parallel to improve throughput and allowed the JIPS CS runs to complete in two weeks

versus five weeks if stand alone servers were used. In addition to parallel processing, HPC nodes were used as distributed database servers to allow for faster processing of raw data to generate outputs per the JIPS metrics.

Table 1 statistics illustrate the huge volume of data and number of runs processed on the HPC nodes. Scripts were written to automate processes for controlling the runs, when to change the dependent variables, and reduce the amount of human interactions necessary to generate the final output graphics. Of note, the statistics below do not account for the number of runs produced during spiral and integration testing.

Table 1. JIPS volume statistics metrics

JIPS CS Stats	
Number of Records Output	180,000
Number of Runs	2700
Number of Solutions	6
Total compressed storage	7.5 Tera Bytes
Number of Databases	2700

DESIGN CONSTRUCT

Department of Defense Architecture Framework (DODAF) views of several real world operational command and control (C2) structures were used to determine JIPS's C2 organizational construct (DoD 2010). This means that hybrid DODAF views of theater specific sensor and network combinations became the blueprint for building the battlefield geometry implemented in the CS. To establish a means for comparing the potential impact of the proposed solutions that were implemented in the process models, two hybrid architectures were created. First there was a baseline architecture that represents current capabilities and processes. Then there was an experimental architecture developed to accommodate anticipated mid-term technology advances. Both these architectures were replicated in the constructive environment.

Five storylines, selected from the 17 originally created storylines, provided descriptions of the geographic locations and typical cultural activities. These descriptions provided the necessary interactions to test out the proposed six solutions. Independent variables established via three sets of weather conditions and three

sensor packages were used to influence the experiment's dependent variables. Additionally, the Master Scenario Event List (MSEL) included the daily collection Request For Information (RFIs) taskings, which represented the implementation of a deliberate collection plan for the various sensor packages used in the trials. Further, the MSELs provided tips which generated cues, which were implemented as changes to the daily deliberate plan. The tips were Intel injects that triggered the re-tasking of sensor assets that were read into the M&S as daily air and ground tasking orders. The cues were sensors adjustments in response to the tips. The RFIs and tips were fed into the multiple models that implemented the human decision making processes for the baseline, experimental architecture and each solution. In turn, the JIPS scenario was the summation of artifacts that provided the environmental conditions for implementation in the M&S.

The degree that the replicated sensors could maintain PS of these cues was what generated the objective and quantitative metrics of interest for the analysts. Multiple runs for each combination of solution were based on storyline, weather and sensor packages and process model produced planning time values. The results of these runs were aggregated to trails based on the solutions, and the HPC was used to assist in the data analyses due to the sheer volume that each trial generated. Hundreds of iterations were done to calibrate the baselines and each solution run before executing the final runs for record. While a detailed discussion of the testing, verification, and validation are outside the scope of this paper, key configuration control issues are discussed below.

Constructive Model

G2 is the process modeling application that was used to replicate the human decision making processes and organizational structures when a re-tasking of a sensor may be required per execution of the JIPS scenario. A hybrid DODAF architecture, replicating four echelons of C2, served as the blueprint for implementing the G2 model. These echelons were: national, Joint Task Force, division, and brigade combat team. Each echelon had independent representation of the human decision making processes for reacting to tips that were introduced by the MSELs. Based on the outcome of the independently running decision

making processes, each echelon had the ability to redirect assets from the RFI taskings to address the emerging requirements. These assets were either dedicated to each of the four echelons, or calls were made to other echelons for additional assets. The selection of which assets for re-tasking was directly dependent on the priority given to addressing the tip. The assignment and allocation of assets against these emerging requirements occurred in the constructive simulation as addressed below.

Expert judgment was used to determine the processing delays or roadblock for the individual nodes in the respective process models. In turn, G2 models were created to support each proposed solution. Based on the implementation of the current solution under investigation for each cue, G2 replicated the decision if a re-tasking was warranted. G2 generated the delay time associated with this decision. This delay time was called the actual duration planning (ADP) time. For the events requiring a re-tasking, these ADP times were passed to the simulation to trigger the potential changes in the collection system, but the simulation was used to determine the asset's availability before executing the re-tasking. Based on the solutions, G2 implementation of the human decision making caused different interactions among the echelons which resulted in varying ADP times.

Constructive Simulation

Simulation of the Locations and Attack of Mobile Enemy Missiles (SLAMEM) was the entity-level simulation used in the CS trails, and served as a federate for the HITL JIPS activities.

SLAMEM's DoD-wide acceptance as a useful simulation for analyzing the performance of coordinated sensor and targeting systems against time-critical mobile targets was the primary reason why the USJFCOM Experimentation Directorate selected SLAMEM to support the JIPS activities. For the JIPS CS runs, a special version of SLAMEM was engineered to run specifically on the HPC that replicated the collection assets as specified by the hybrid DODAF views. SLAMEM simulated the actions of platforms carrying sensors and the articulate components of the sensors to execute the deliberately planned RFI asset taskings in a constructive environment. These RFI taskings represented the pre-planned collection activities that were executed by collection assets, which replicated sensors mounted on the respective delivery platform. Thus, SLAMEM represented the battlefield geometry that the analysts could measure the success of the proposed solutions against.

The experimentability of the JIPS problem domain depended on the simulation's ability to generate data to understand the causality as adjustments were made to the RFI taskings. In turn, whenever SLAMEM adjusted the RFI tasking to accommodate the emerging re-tasking requests, which were spawned by tips that were generated from predetermined storylines and MSEL items, SLAMEM captured appropriate interactions/measures in logs. The number and content of Intel injects fed into G2 were held constant across the solutions. Once G2 delays were applied, some MSEL items were discarded before reaching SLAMEM. The number of items that were discarded varied among the runs.

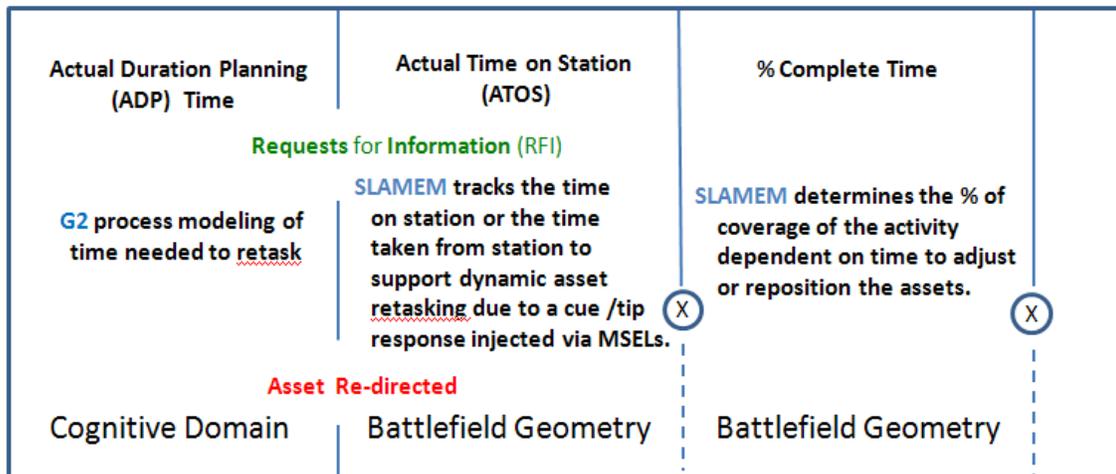


Figure 1. How CS metrics aggregate into measures of interest

Combining Model and Simulation

Figure 1 summarizes the intended use of G2 and SLAMEM to support the analysis of the proposed JIPS solutions. Three columns represent which M&S was used to provide useful data. Three primary measures were used in the HPC calculations: ADP, Actual Time on Station (ATOS), and the % Complete Time (CT). While ATOS provided meaningful insights, the CT measure was the metric of primary interest. In the figure, there is a detailed explanation of how the M&S was used to generate these three measures. Additionally, the figure specifies where the representation of the cognitive domain ended, and where the constraints of physics started. These constraints defined the battlefield geometry that specified the available angles and distances that directly impacted the sensors' ability to acquire their targets. The degree that a target was spotted, recognized and/or identified was influenced by a series of SLAMEM algorithms collectively called the confusion matrix. Also gathered was how much detail could be gathered during any asset's ATOS.

Basically, it was the delta between the RFIs and the re-tasked collections that determined how much of an impact the proposed solutions had on the supported PS processes. SLAMEM mapped the coverage footprints for the respective articulate parts of the sensors that gathered the signatures of the activities of interest. SLAMEM determined the percentage of coverage that persistent surveillance (PS) was able to achieve. However, there were more JIPS measures of interest than just ADP, ATOS and CT.

METRICS GUIDING INTENDED USE

In reality, the M&S generated two classes of metrics that relate to performance and effectiveness. These classes of metrics become the indicators that their presence or lack of presence provided insights into the solutions' optimization (Sokolowski, 2006). The following section discusses how the data collected in the SLAMEM logs and the G2 variables were used to compute the three key measures discussed above.

First Class of Metrics

The first class of metrics assessed the overall effectiveness of the collection planning process.

Called collection assessment (CA) metrics, they serve to measure the effectiveness of each of the implemented solutions. For example, one CA metric involved counting collection requests against each type of collection requirements (CR). SLAMEM generated the CA metrics. Some of the different types of CRs are listed below. In essence, a CR was a SLAMEM call to look at a particular area on the ground for a particular extent of time with a sensor that provides a certain level of resolution and capability. There are two entries for each CR, one when the collection request started and a second one when it ended. These metrics were captured in a SLAMEM log that were post-processed by the HPC and written out in formats pre-defined by the analysts.

The different types of CRs include the following five items. These categories were necessary to assist in defining the metrics to determine the differences among the implementations of the various solutions.

- Preplanned: Original collection requests that are assigned when the sensor platform takes off or a mission starts.

- Retasked: Collection requests generated as follow-up actions to other collection requests.

- Ad-hoc: New collection requests generated by ground units that need support for their missions.

- Cued: New collection requests generated from tips and other Intel sources including external sensors.

- Resubmitted: Collection requests that are resubmitted when the requestor does not feel they are getting sufficient response to their original request, typically an Ad-hoc request.

To allow analysts to separate out the different types of CRs in the SLAMEM log, a standard naming convention was adopted. In turn, each preplanned calls started with PRE, all re-tasked calls started with RET, all cued calls start with CUE, all re-submitted calls start with RES, and all Ad-hoc calls started with ADH. The next three letters in the log entries were used to indicate the echelon from which the request originated from NAT for national, JTF for Joint Task Force, DIV for division, and BCT for brigade combat team.

Exemplar Metrics

Six solutions were implemented for the JIPS experiment against two baselines. These solutions were implemented in the G2 model, and the results were captured from the SLAMEM outputs. One of the six solutions required the tracking of CRs across all the echelons. This solution analyzed the impact on visibility, prioritization and completion status of the CRs if a critical process was changed. For this solution, the critical process was when the elimination of redundant CRs should best occur. The options for the elimination were either at the beginning or at the end of the sensor re-tasking cycle for a particular solution. What the solution showed was the causality between the reduction in unintentionally redundant CRs tasked and the number of hours saved by eliminating unintentionally redundant RFIs early or late in the planning cycle.

This solution's implementation required the execution of SLAMEM with baseline delay times. Redundant RFIs were identified without being influenced by the tips that entered into the system via the MSELs. Redundancy occurred when any portion of a RFI's sensor's footprint overlapped the same coverage of at least one other RFI. Then the MSELs were fed into G2 with a 10% reduction in the redundancies before

the solution was implemented in G2. This 10% figure was an estimate of a human decision making factor as the function of a human's perception of the problem, commander's intent and priority. The 10% value reflected the number of times a human would consider a task redundant. Elimination was conducted in a stochastic manner. This activity generated a new reader file unique to the solution. Then this solution was re-run in SLAMEM to determine the impact of the early elimination of ten percent of the redundancies as opposed to conducting the elimination at the end of the G2 implemented solution. In this manner, the planning process (PP) metrics concerning the number of PRE CRs, which were affected by the ADHs and CUEs, were used to explore if removing the redundancies before the planning process would result in any improvements in the CA metrics. Figure 2 illustrates where in the CS process the echelons and the first class of metrics were executed.

Second Class of Metrics

The second class of metrics assessed the planning process to determine if a tip was significant enough to cause a re-tasking of an asset represented in SLAMEM. By starting

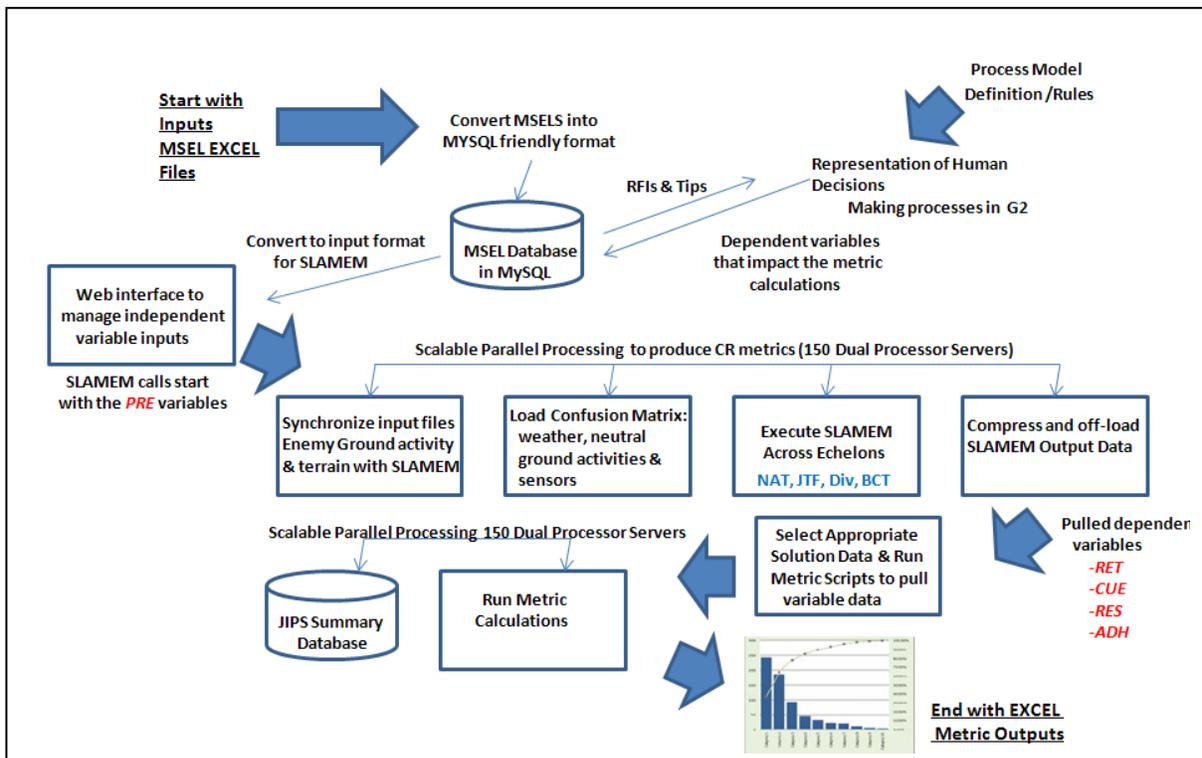


Figure 2. End to end CS processes to produce metric outputs

calculations with the PP metrics, they served to measure improvements in how quickly a re-tasking was requested to be executed in SLAMEM. The metrics allowed analysis of each solution as compared to the baseline runs. For this experiment, effectiveness was narrowly defined as the number of CRs collected on, the overall percentage of completion of CRs, and the periods of surveillance coverage and gaps. As stated above, G2 metrics were combined to generate a series of solution specific ADP delay times as one of the PP metrics. Then each SLAMEM run started with the ADP metric to gather data that was used to compute ATOS and CT.

Per figure 2, the HPC CS runs began with the creation of the MSEL database (DB) in MySQL. The MSELs were inputted in Excel spreadsheets formats that were read into the DB. Then based on the G2 implemented solution specific rule sets, the planning times to react to the various MSEL identified tips were used to update the MSEL DB. The MSEL items represented the friendly forces reaction to the tips and the PRE variables. Then a web interface was used to initialize SLAMEM with the updated DB values, the load was spread across 150 HPC dual processors. While the HPC had additional nodes, there were only a portion of them dedicated to support the classified JIPS simulation runs. This allowed USJFCOM the capability to run a portion of the HPC in an unclassified mode to support other efforts.

Many automated activities occurred to support

each run. First, the activities of interest for PS and the terrain files were synchronized with the friendly activities that were updated in the MSEL DB. In parallel, the confusion matrix variables were loaded that defined weather, the neutral ground activities and the appropriate sensor package. Three separate sensor packages were used to assist in differentiating current and near term capabilities in regards to implications of the different solutions.

Next SLAMEM executed and the output CR metrics of RET, CUE, RES and ADH were substantiated. Here, SLAMEM calculated the battlefield geometry for each observation based on the acquisition angles of the sensors mounted on their respective platform, and the terrain masking affects that limited line-of-sight calculations. Re-positioning of the platforms were generated by re-taskings that were spawned from the MSELs with respect to the priority each re-tasking was given based on pre-defined rules.

Scripts were then run to pull variables from data fields of interest and provide them to the HPC nodes for post-processing runs and storage. Post processing was needed as the storage on the data during execution rapidly exceeded the available memory. This post-processing created a summary JIPS MySQL DB. Finally, scripts were used to automate the building of output metrics in Excel formats. These runs represented 14 days of continuous operations in a current operational environment built from hybrid architectures as previously discussed.

Architecture	Solution	Storyline	Weather	Sensor Packages	Total Runs
Baseline	0	2,3,4,15,17	1,2,3	A,B,C	45
LOO1	1A,1B,1C	2,3,4,15,17	1,2,3	A,B,C	135
LOO2	2A,2B	2,3,4,15,17	1,2,3	A,B,C	90
LOO4	4A	2,3,4,15,17	1,2,3	A,B,C	45
Experiment	0	2,3,4,15,17	1,2,3	C	15
LOO1	1A,1B,1C	2,3,4,15,17	1,2,3	C	45
LOO2	2A,2B	2,3,4,15,17	1,2,3	C	30
LOO4	4A	2,3,4,15,17	1,2,3	C	15
	Hybrid	2,3,4,15,17 & combos	1,2,3	A,B,C	As desired

Figure 3. Example of a run matrix to control the numerous dependent variables

Additionally, the JIPS solutions were organized along four Lines Of Operation (LOO). The analysts used the LOOs to organize the output data as certain solutions only supported certain LOOs. These LOOs provided the functional context that assisted in setting up the CS and HITL runs. For example, one LOO was only executed during the JIPS HITL; this was because LOO3 required the observation of human interaction, stimulated by the M&S, to generate data of interest. Further, this four LOO construct allowed analysts to determine where they could reduce the number of runs necessary to produce statistically significant data. This reduction in the number of CS runs directly decreased the volume of output data that the analysts had to review. In other words, the LOOs assisted in defined how the intended use of the M&S, implemented via the solutions, could be evaluated against the JIPS problem statement. While discussion of the actual language of the LOOs is outside the scope of this paper, figure 3 highlights that the different solutions did not execute for each run. In essence, the CS assisted in pointing a way for how analysts collected data sufficient to support the DCAP specified JIPS metrics.

LESSONS LEARNED

Many lessons were captured in software change requests (SCRs). SCRs were written for every aspect of the JIPS experiment. However, the composition of the scripts used to automate the reading and writing of data among the M&S and data stores presented some interesting challenges. Quality assurance challenges stemmed from having to deal with huge volumes of data that made manual means to conduct logic and consistency checking obsolete. In turn, simple analytical techniques, such as pivot tables, were used to map ADP times against tips that generated CUE events to determine if the setup files were correctly loaded for the solution trails. Due to the huge number of dependent and independent variables from thousands of data entries, the simplest checks served to locate setup errors that could be rectified in subsequent CS runs. However, no testing technique proved better than having the PS subject matter experts, analysts and modelers simultaneously walking through the G2 models to get agreement on process design and functionality.

In regards to the coupling of CS and HITL simulation activities, the implementation of time had the greatest impact on the intended use of the HITL simulation. For example, certain sensor assets were capable of transmitting full motion video (FMV). However, the CS trials only implicitly represented the multiple FMV feeds. Thus, JIPS HITL trials required rigorous testing and adjustments to ensure that the FMV taskings, transmissions, and routings all occurred within the proper time horizons, which were influenced by the G2 model metrics. Testing and adjustments of certain activities that were only implicitly implemented in the CS, but were explicitly executed in the HITL trials, did cause the analysts to review and have the modelers update the CS models. However, these model updates were expected under the umbrella of the M-W-M paradigm, and the adjusted metrics were incorporated in the post-HITL runs in the CS environment.

Figure 3 shows a Run Matrix example that highlights the complexity associated with M&S setup discussed in figure 2. For each LOO, different solutions and sensor packages were run against the same three weather conditions. LOOs were used to help organize the inputs and outputs into smaller data sets. Analysts determined the number of runs needed to develop statistically significant data to support the analytical findings. Then the M&S support team applied much needed automation that allowed the analysts to rapidly re-do runs on demand. This automation greatly reduced the time needed to gather sufficient data to support the findings. This ability to rapidly re-do runs served to compress a potential multi-year CS activity into one spanning a year. In turn, having an ability to control and rapidly manipulate the numerous dependent and independent variables, as specified in the supporting DCAP, was the greatest lesson learned from this innovative HPC experiment.

CONCLUSION

In summary, this paper described how an entity-based simulation was re-engineered and coupled with a process model to meet the requirements of a recently executed M&S activity. This activity was associated with a JCD&E sponsored joint experiment, and executed utilizing the M-W-M paradigm. For this paradigm, simulations were adapted to run in FTRT modes with the

assistance of USJFCOM's HPC. Then insights from the CS were used to inform the HITL trials, and subsequent CS runs that were executed post-HITL. Useful in post-processing as well as timely execution, the HPC allowed excursions in constructive environments what would have been otherwise prohibitive in real-world field experiments. It was via the innovative use of USJFCOM's HPC that allowed the necessary control of input and output data which produced the quantitative and objective measures that were used to develop the metrics specified in the supporting JIPS DCAP. Thus, the CS results were used to point the way for finding supporting data that addressed the metrics developed by the analysts. In some cases, models had to be modified and re-run to ensure the metrics were properly addressed, and it was the M&S that provided the simulated environments in which those metrics were captured.

Given that future military engagements will require an increased dependency on coordinating and synchronizing the multiple sources of available information and intelligence, and identifying what new sources are needed, then innovative approaches must be continuously explored to more rapidly field solutions to our warfighters. While experiments such as JIPS, currently allow the decomposition of experiments involving information and intelligence investigations into hundreds of independent and dependent variables, longer term project views are necessary. As the application of USJFCOM's HPC to support JCD&E projects has shortened the completion time of individual projects, the possibility of overcoming the issues stemming from the complexity of closely coupling JCD&E M&S project outcomes, via the JCD&E campaign plan, now becomes achievable. In other words, the only limitation on future M&S supported joint experiments will be the imagination of the next generation of planners. This is because the technology exists to support CS supported experiments as complex as planners need to design them.

Therefore, the significance of this experiment was that JIPS successfully dealt with the complexity of rapidly changing and adjusting independent and dependent variables, which allowed the project team to make the experiment as relevant as possible for the warfighter. Using custom made setup matrices to feed huge

volumes of data into the HPC supported constructive M&S environments made it possible to fine tune the scenarios, G2 models and SLAMEM to achieve the required analytical rigor while still being able to plan, setup, execute and access outcomes within the JCD&E experimentation timetable.

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