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"C2 for Complex Endeavors"

Experimentation via the Use of an Executable Workflow Model to Evaluate C2 Decision Quality

C2 Experimentation
C2 Modeling and Simulation
Network-centric Metrics

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Abstract

This paper presents results of a Johns Hopkins University Applied Physics Laboratory (JHU/APL) multi-year command and control (C2) evaluation project. Results were based on experimentation conducted in FY07 to evaluate C2 decision quality during the execution of an emulated Prompt Global Strike (PGS) process via the use of an executable workflow model. The model characterized the activities of the Transition-To-Target (TTT) phase of the PGS process. It represented the sequencing relationships among the phase elements in the form of a workflow. Execution of the model drove a visual representation of workflow completion status, which was used to synchronize the actual conduct of the process by participants in response to a series of scenario-driven events. The model was also used to automatically record the responses of participants as they monitored execution of the TTT phase of the PGS, which were later used to analyze the effects of certain types of event data on the quality of decisions made by the participants during experimentation. Our experimental results demonstrated that our evaluation framework, and in particular, the use of an executable workflow model served as an effective means for evaluating decision quality associated with C2 processes.

1. INTRODUCTION

1.1 Background

This paper presents the results of a Johns Hopkins University Applied Physics Laboratory (JHU/APL) multi-year, independent research and development (IR&D), command and control (C2) evaluation project. The purpose of the project is to develop methods, within the context of an evaluation framework referred to as the Multi-resolution Modeling Evaluation Framework (MRMEF) (References 1-3), for evaluating whether or not the application of net-centric principles to command and control improves the effectiveness and efficiency of C2. This year's effort focused on conducting experimentation to evaluate C2 decision quality during execution of an emulated prompt Global Strike (PGS) process via the use of an executable workflow model.

1.2 Scope

The scope of this paper includes a brief description of the MRMEF, which is more fully described in the references cited above. It discusses the use and importance of process decomposition to the overall approach of evaluating C2 capabilities and presents high-level examples of decomposition as it applies to the PGS process in general and more specifically, to the Transition-To-Target (TTT) phase of that process, which served as the contextual basis for this year's experimentation effort. It describes how a decomposed process can be translated into an operational workflow by applying sequencing relationships to process elements. When modeled, the executable form of that workflow can be used to drive and control the conduct of a mission, such as a PGS, and facilitate the automated collection of data related to the completion of operational tasks associated with that mission. It further presents details of the FY07 experiment, which includes descriptions of the scenario, the experimentation environment, the experimental design, and experimentation results. Finally, the paper presents conclusions based on those results and a brief description of our planned C2 research efforts in FY08.

1.3 Net-centric C2 Evaluation Description

Several key elements, listed below, are considered to be significant enablers for the successful evaluation of net-centric C2. Those elements are described in detail in the following paragraphs.

- Multi-resolution Modeling Evaluation Framework (MRMEF)
- Process Decomposition and Assessment
- Workflow Modeling

1.3.1 Multi-resolution Modeling Evaluation Framework (MRMEF)

The MRMEF was developed to serve as our foundational basis for evaluating net-centric C2. It utilizes constructive, virtual, and live simulations and hardware-, software-, and humans-in-the-loop, where appropriate, to support that evaluation. Multi-resolution Modeling (MRM) has many advantages over more traditional approaches for analyzing C2. It has been successful because it has the characteristics needed to solve difficult analysis problems by integrating information

achieved with high-fidelity models and generalizing the results and implications via a low-resolution model (Reference 4). An overview of the MRMEF is shown in Figure 1. A brief summary of the MRMEF is provided in Appendix A.

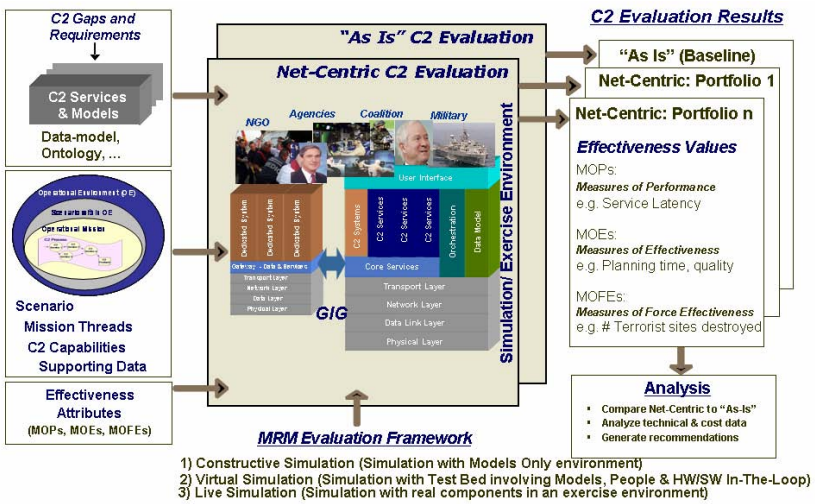


Figure 1. Multi-resolution Modeling (MRM) Evaluation Framework (MRMEF)

1.3.2 Process Decomposition and Assessment

One of the requisite enablers for the successful analysis and evaluation of C2 and a key element of the MRMEF is the ability to decompose C2 processes in the context of a mission domain. Our research this year focused on C2 as it applies to PGS, one of the mission areas for which the U.S. Strategic Command (USSTRATCOM) has responsibility. The relationship of that and other USSTRATCOM mission areas and their associated cross-cutting functional capabilities, of which C2 is apart, is depicted in Figure 2.

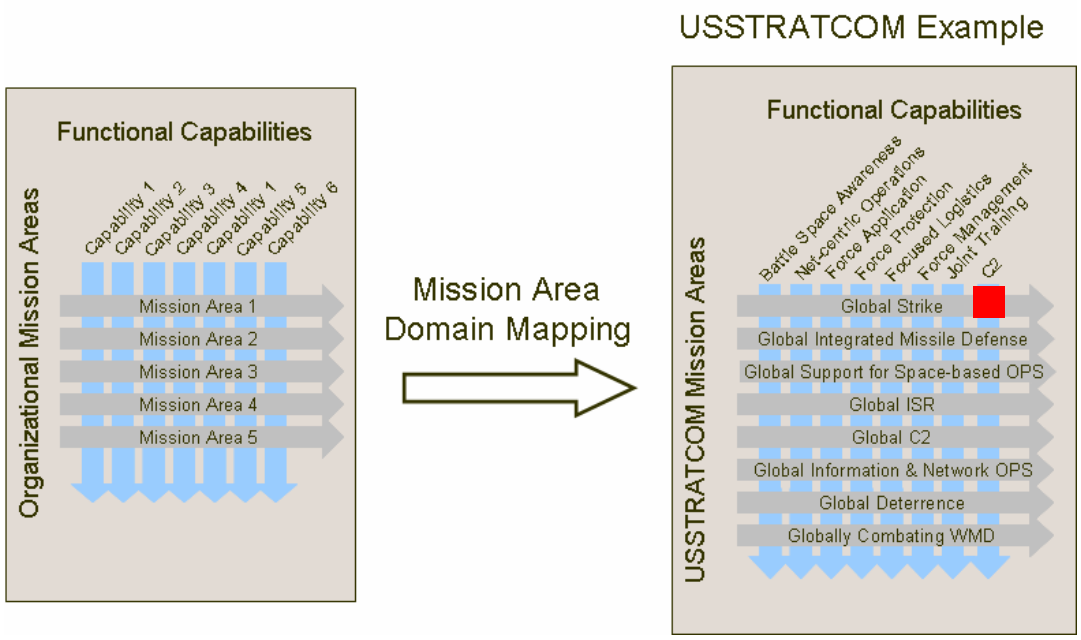


Figure 2. Mission Area/Cross-cutting Functional Capability Mapping

In 2005, USSTRATCOM initiated an effort to decompose its Global Strike mission area and associated C2 functional capabilities into processes. That decomposition resulted in the establishment of three top level process elements, which consisted of Adaptive Planning, Crisis Action Planning, and Execution. From those elements, a detailed Global Strike/C2 activity model was derived. That model established relationships among the process elements and also provided a limited characterization of process activity times based on the qualitative input of subject matter experts (SMEs). Since that time, the application of net-centric principles to Global Strike has resulted in a modification to the manner in which Global Strike is conducted and managed. Global Strike processes, during FY06, were represented in the form of a process workflow contained within a web-based, portal environment referred to as the Global Operations Center Collaborative Environment (GOC-CE). The GOC-CE was used to coordinate and facilitate joint collaboration during the conduct of Global Strike experiment, exercises, and operations. However, during the past year, that capability was superseded by the deployment of the Integrated Systems Planning and Analysis Network (ISPAN) Collaborative Information Environment (CIE), the next generation portal-based environment for PGS planning and execution monitoring.

Our research effort was limited to use of the GOC-CE, which we imported from USSTRATCOM into our experimentation environment. We augmented the GOG-CE with TTT workflow, the second of four PGS execution phases (Figure 3). Our experimentation was centered on that phase of operations.

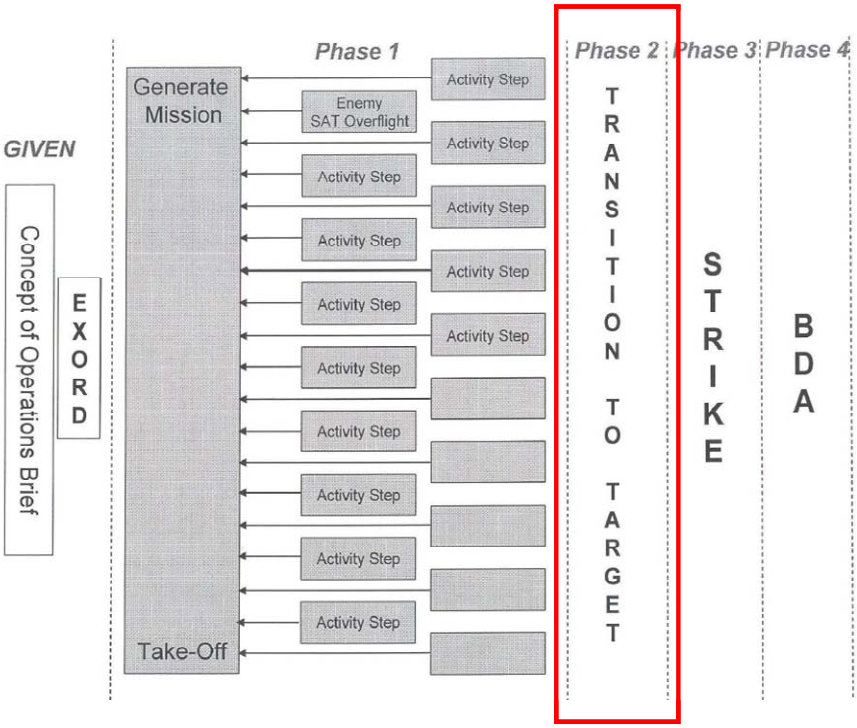


Figure 3. Relationship of “Transition-To-Target” to the other PGS Execution Phases

1.3.3 Workflow Modeling

Another key element of the MRMEF is the ability to model and simulate mission workflow. We augmented the PGS activity/process model by including sequential relationships among the process elements to generate a separate Global Strike workflow model. Based on that model, we developed two additional experimentation products. The first was a simulation, developed using the Telelogic ProcessModel ™ tool, to demonstrate the flow of the Global Strike process over time. The simulation supported "what-if" analysis, which allowed us to change the workflow in a structured, repeatable manner by adding increased parallelism, automation, etc. to determine if those changes increased its temporal efficiency. Based on that work, we selected the TTT phase of the PGS for further evaluation and experimentation. To support that effort, we developed a second product, a real-time, executable workflow model (EWM) of the TTT phase of PGS using Microsoft's Windows Workflow Foundation (WF) software. That model supported an onboard knowledgebase capable of storing either simulated or historical workflow element completion times that were used to drive the rate at which the workflow was executed during the conduct of a scenario-based, Global Strike mission. Real-time execution status of the EWM, e.g. time remaining to complete a task, was provided to exercise participants who were responsible for completing actual TTT workflow elements during experimentation. Status was provided to them in the form of visual cues, i.e. color-coded status bars, via an instrumented interface between the EWM and the GOG-CE portal (Figure 4). The model was also used to automatically record the responses of participants as they monitored execution of the TTT phase of the PGS, which were later used to analyze the effects of scenario data consistency, relevancy, and timeliness on the quality of decisions made by the participants during experimentation.

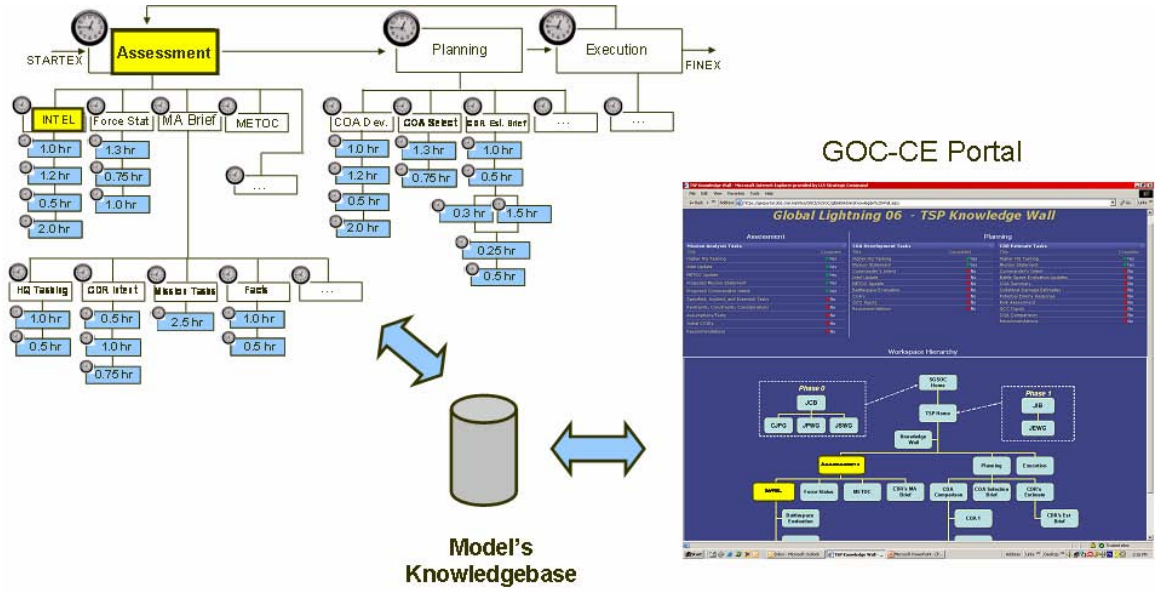


Figure 4. Partial representation of the visual status interface between the EWM and the GOC-CE

2. FY07 C2 EXPERIMENTATION

The overall goal of our experimentation effort was to develop the ability to perform an end-to-end independent evaluation of C2. The set of objectives developed to support that goal were:

- To demonstrate that the workflow model and its instrumented interface to the GOC-CE are an effective means for visualizing mission workflow status and for automatically collecting data to support post experimentation analysis and reporting
- To demonstrate that data products associated with a set of scenario-based events could be automatically injected into the experimentation environment to stimulate warfighter participant response to those events in a controlled, consistent manner
- To demonstrate the ability to measure the effects of scenario data consistency, relevancy, and timeliness on the decision quality of participating warfighter role players in a pseudo-realistic operational environment

2.1 Hypothesis

To meet the goal and objectives stated above, we established the boundaries of our experiment by defining a hypothesis, which focused on C2 decision quality. We also created a supporting scenario, which served as the contextual basis for testing that hypothesis. Our hypothesis was:

"**C2 decision quality is improved with increased data consistency, data relevancy, and data timeliness**".

The terms within the hypothesis statement are defined as follows:

- Consistency – degree to which data either supports, or does not support the mission
- Relevancy - significance of the data to making a mission related decision, i.e. degree to which extraneous mission data is excluded
- Timeliness – condition when all required information necessary to make a decision was received within the first 13 minutes (87%) of a 15 minute experiment repetition

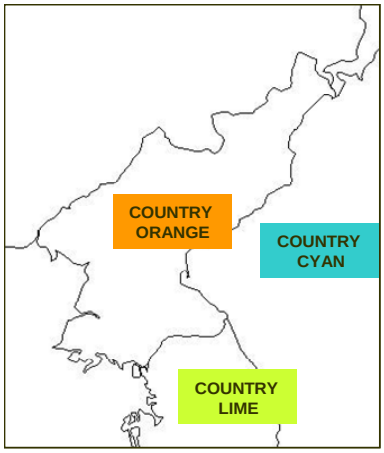
Note, a more detailed discussion regarding these terms is provided in Section 2.5.

2.2 Scenario

The high-level storyboard (HLS) version of the scenario, which was created to support our experimentation, is described below in Section 2.2.1. A more detailed decomposition of the HLS was generated to provide specific event data to each of the warfighter role players who participated in the experimentation. Those events were constructed in the form of Master Scenario Event List (MSEL), which is a set of events the structure of which was based on our experimental design.

2.2.1 High-level Storyboard Scenario Description

Regional tensions with Country Orange have increased. Country Orange has recently escalated its 'brinksmanship' diplomatic style by threatening to launch inter continental ballistic missiles (ICBMs) as a show of resolve and recently Country Orange announced it will conduct test launches. The true intentions of Country Orange are unknown. The facility where the launches are likely to occur is capable of supporting short, medium, and ICBM launches. That information is based on activity detected in the vicinity and prior intelligence data.



There is concern that Country Orange will launch missiles equipped with warheads, which could be chemical in nature. Intelligence sources indicate that Weapons of Mass destruction (WMD) warheads are co-located with the ICBM launch facility and that a WMD warhead has been mated to an ICBM, although this cannot be positively confirmed. Targets have not been explicitly identified, although probable targets are conjectured.

A "Carrot Then Stick" approach that involves simultaneous non-kinetic deterrence paired with a Global Strike effort was adopted as the selected "blended" course of action (COA). The Warning Order has been issued and COA development initiated. The U.S. Pacific Command (USPACOM) is the designated Supported Commander with USSRATCOM in a supporting role. A Joint Task Force (JTF) Commander embarked on-board the USS Blue Ridge is tasked with commanding the operation. Commander's guidance states that a non-kinetic resolution is desirable, but that a Global Strike should be executed if it appears that Country Orange is about to launch missiles equipped with warheads against "friendly" targets. USPACOM is supporting the Department of State during its negotiations with Country Orange to deter the missile launches. Meanwhile, JTF Operation Iron Hammer has regional as well as some national Intelligence, Surveillance, and Reconnaissance (ISR) assets focused on the problem.

Three Global Strike COAs were initially identified for mission consideration. The weapon system for those COAs was a Tactical Tomahawk Land Attack Missile (TTLAM), B1-Bomber and tactical Air (TACAir), respectively. The COA involving the TTLAM was selected as the primary COA option.

The experimentation scenario begins under the conditions where the non-kinetic deterrence option has been unsuccessful to date and Phase 2 of Global Strike Execution, i.e. the TTT phase of execution, has been initiated. That phase refers to the condition where the TTLAM is flying towards the target and mission conditions such as weather, status of the weapon, etc., are being monitored for appropriate status returns to allow the JTF Commander to make a decision regarding whether the mission should continue to completion. The readiness status of the contingency Global Strike COAs is being monitored. Several related or possibly unrelated events complicate the situation. Country Lime announced it will send 400,000 tons of rice to Country

Orange to foster good relations and hopefully aid on-going negotiations. The supplies will be delivered by ship. At the same time, Country Orange launches several test missiles. A Special Operations Force (SOF) team is deployed into Country Orange to conduct targeting and subsequent Battle Damage Assessment at the missile launch site. The SOF team discerns that the target location initially specified for TTLAM strike may in fact be a decoy; a new launch site or equivalent high priority target is therefore identified. The SOF team provides target information and the TTLAM is redirected against the new target. Meanwhile, a Country Orange SOF team is detected infiltrating the northern border of Country Lime. The JTF must determine whether this activity is related to the missile launches and assess the impact on the current operation.

2.3 Experimentation CONOPS

Our experimentation plan consisted of a twelve-replication experiment, which was conducted during the week of 24 – 28 September 2007. The duration of each replication was fifteen minutes in length. Seven warfighter role players were used to support the experiment. Those roles consisted of a Joint Task Force (JTF) Commander and six functional area specialists whose role was to monitor the execution of the TTT phase from their individual functional perspective and provide status to the JTF Commander in the following functional areas: Meteorological and Oceanographic (METOC), Blue Force Tracking (BFT), Target, Strike Asset, Support Asset, and Battle Damage Assessment (BDA). Throughout each 15-minute replication, the JTF Commander maintained situational awareness in order to make a Go/No-Go determination regarding continuation of the Global Strike mission. Each of the six functional role players were provided scenario-driven event data, which served as stimuli to elicit their decisions regarding the quality of the data they were receiving and whether or not that data supported continuation of the mission. Their individual decisions were in turn provided to the JTF Commander to help facilitate his/her situational awareness regarding the mission. The following Tactics, Techniques and Procedures (TTPs) were defined for each experimental repetition:

- At the start of the exercise (STARTEX), the six functional role players were conducting monitoring activities to support the TTT phase of operations.

- Each functional role player was provided scenario event data from one of four possible MSEL files via web parts embedded in web pages within the GOC-CE environment. Each player had 7.5 minutes to make initial assessments regarding the quality of data to which they were exposed and the impact of that data on the overall execution of the mission. Any of the functional role players could update their respective assessments throughout the 15 minute timeframe until the JTF Commander made the final Go/No-Go decision at mission FINEX.

- Roles among players and event data to which the players were exposed from the MSEL files were structured to minimize the “learning effect” of participants during experimentation, i.e. no participant played the same role with the same set of input data more than once.

- Each functional role player and the JTF Commander were provided a set of "rules" to help guide their decisions about data quality and mission continuation support. For example, from a METOC perspective, data quality was considered to be "good" if the data was consistent, and the mission could proceed as planned if the low altitude wind speed over the target area was less than 14 knots, the wind speed at 1000 ft. was less than 20 knots, and no thunderstorms or icing conditions were present in the area.

- At the end of the initial 7.5-minute window, the JTF Commander expected all functional role players to have provided him/her their initial data quality and mission support assessments.

- The experiment replication ended after 15 minutes when the final Go/No-Go mission support decision was made.

2.4 Experimentation Environment

2.4.1 JHU/APL GIG Test Bed

To support this and other related research projects, JHU/APL created a Global Information Grid (GIG) Test Bed, hereafter referred to as the Test Bed, which emulates GIG-like functionality. It supports the development and evaluation of net-centric services and capabilities in a GIG-enabled environment. It was developed based on a set of components designed to emulate GIG-enabled service-oriented-architectures (SOAs) by establishing an agile, reconfigurable infrastructure capable of testing a wide array of GIG implementation and utilization alternatives. It has been and will continue to be used to rigorously characterize GIG emulation fidelity and performance in the areas of transport, computing, and net-centric services**.** A graphical depiction of the FY07 instantiation of the Test Bed is shown in Figure 5.

The Test Bed is externally connected to a point of presence (POP) on the high speed Mid-Atlantic Crossroads (MAX) network (MAXPOP), a consortium of higher education and research institutions in the Washington, D.C. area. The Test Bed will be further extended to include both the unclassified and classified Defense Research and Engineering Networks, i.e. the DREN and S-DREN, respectively. Additional plans are being developed and coordinated to support connectivity to the Secret Internet Protocol Router (SIPRNET) network and connectivity with a number of external experimentation partnering organizations including Space and Naval Warfare (SPAWAR) Charleston, SC and the Electronic Systems Command (ESC).

The Test Bed is the research platform on which the EWM and a working version of the GOC-CE were installed and our C2 hypothesis evaluated.

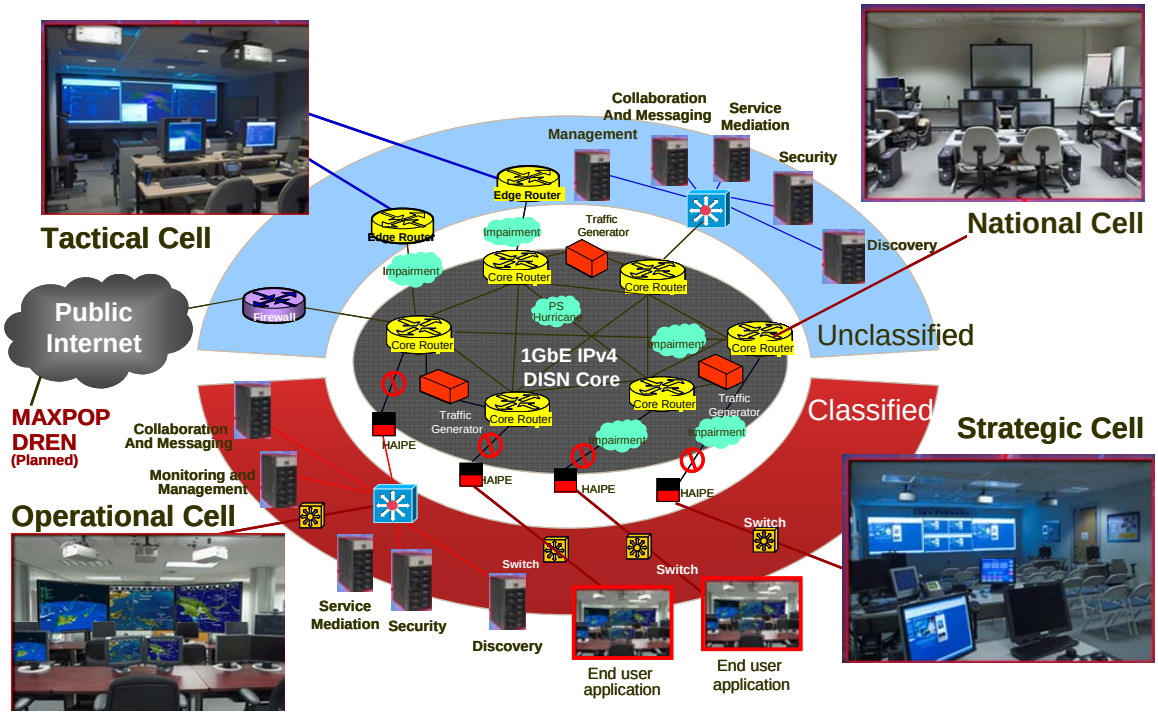


Figure 5. APL GIG Test Bed

2.4.2 Experimentation Tools

A number of tools were used to support our experimentation effort. Those tools are described below.

2.4.2.1 GOC-CE

The Global Operations Center Collaborative Environment (GOC-CE) is a collaborative tool used by USSTRATCOM to plan Global Strike operations. Although, as mentioned previously, the GOC-CE was replaced by the next generation planning tool referred to as ISPAN, we chose to utilize the GOC-CE to minimize the impacts of USSTRATCOM's system development efforts on our research in FY07. We'll revisit the issue of shifting to ISPAN in FY08.

We augmented the GOC-CE to include execution monitoring workflow that specifically focused on the TTT phase of Global Strike execution. The GOC-CE, in concert with an instrumented interface with the executable workflow model, provided visual cues to participating role players regarding the status of execution of the TTT workflow. It also allowed role players to input decision information about the quality of data to which they were exposed and whether or not that data supported continuation of the Global Strike mission. A view of the GOC-CE web page utilized by the JTF Commander to oversee and control mission execution is shown in Figure 6.

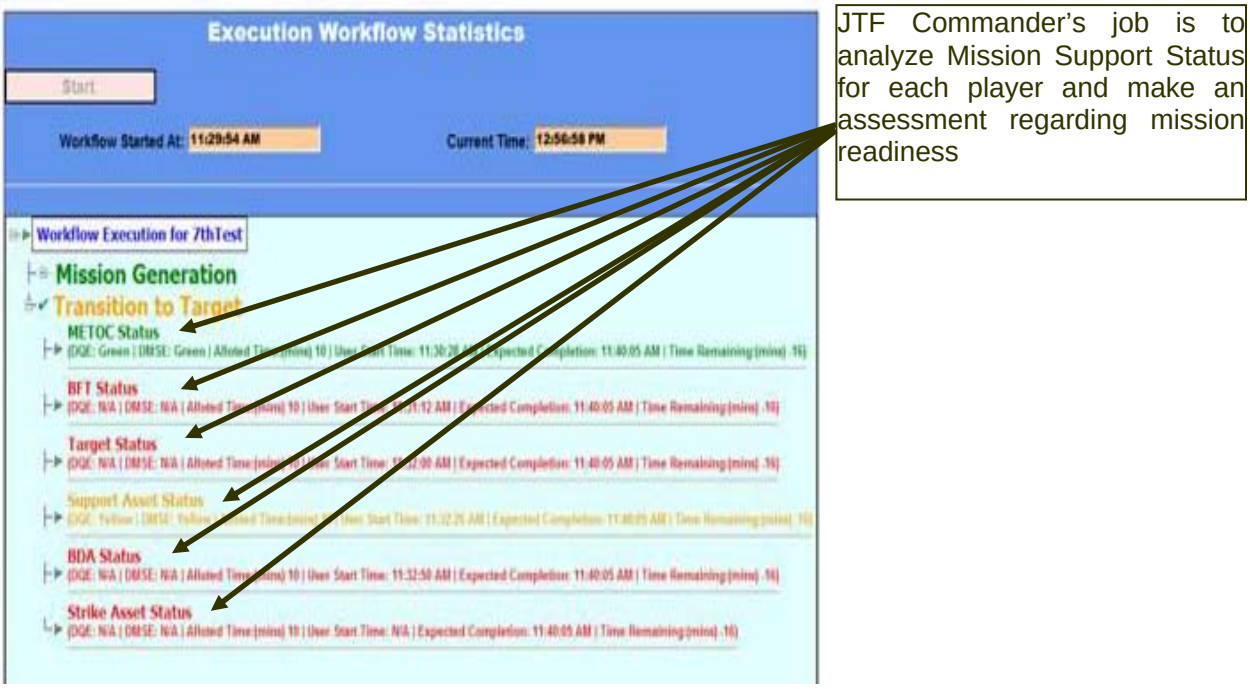


Figure 6. JTF Commander's Mission Control Page in Augmented GOC-CE

2.4.2.2 Executable Workflow Model

The executable workflow model was previously discussed in Section 1.3.3.

2.4.2.3 Scenario Event Generator

We developed an automated tool for injecting Master Scenario Event List (MSEL) data into our experimentation environment to serve as decision-making stimuli for participating role players. That tool, referred to as the MSEL Injector Application (MIA), was developed as a web service, the event data from which was consumed by and displayed in web parts embedded within the GOC-CE. At the startup of each experiment replication, the MIA injected a set of experimental design-controlled events, selected from one of the four available MSEL files, into a unique GOC-CE web page designed for each of the six participating functional role players. That data was tailored for each of the players based on their functional role and was injected over the course of each replication based on timestamp information specified by the experimental design. A graphical depiction of the MIA is shown in Figure 7.

2.4.2.4 CollabSpace

CollabSpace is a JHU/APL-developed visualization product based on the National Aeronautics and Space Administration's World Wind visualization tool. We augmented that tool to be able to consume data generated by external web service data sources. In particular, we used CollabSpace to consume track data generated by the Cooperative Engagement Capability service, a Navy application responsible for visualizing air and sea track data. We utilized that data to provide the

Strike Asset role player decision stimuli regarding the need for air track de-confliction over the scenario target area.

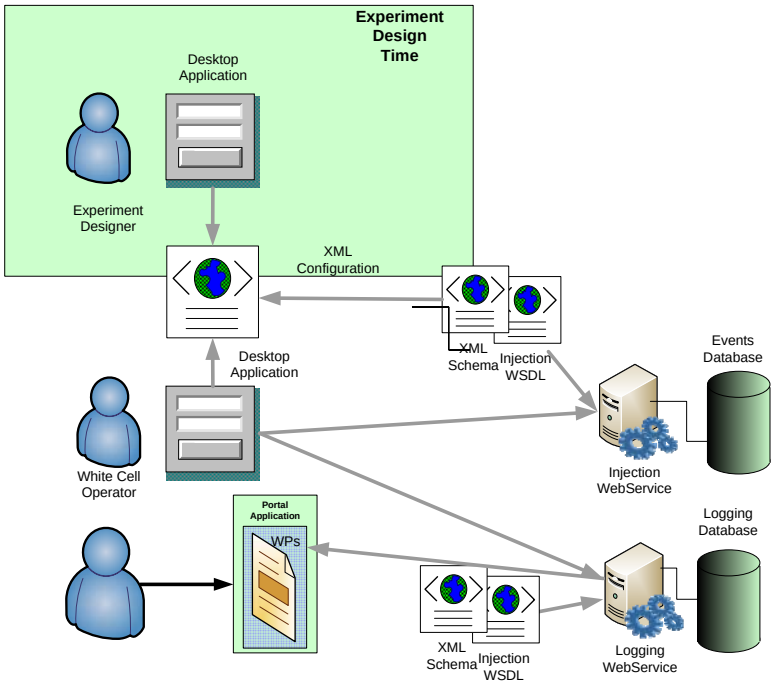


Figure 7. Graphical depiction of the MSEL Injector Application (MIA)

2.4.2.5 InfoWorkspace (IWS)

InfoWorkspace ™ is a commercially available collaboration tool we used to support audio and typed chat between the JTF Commander and the six other functional role players. The JFT Commander used this tool to obtain clarifications regarding the mission status being provided to him/her by each of the role players during the conduct of each replication of the experiment.

2.5 Experimental Design

We used an experimental design to structure our experiment. In our design, the controllable input variables to the experiment were referred to as *factors* and the output performance measures as *responses*. The experiment was designed to minimize the variance in the responses. The ultimate goal was to measure not only the individual effects of the factors, but the effects of their interactions on the responses as well. To accomplish that, the levels of each factor were varied across factor/level combinations and were considered simultaneously. Thus, the design was structured as a *factorial experiment*. The value of this analytic approach is that factors can be examined simultaneously, allowing factor effects and interactions to be estimated and conclusions drawn over a relatively wide range of conditions.

The factors for this experiment and the levels for each factor are described below.

- **Data Consistency** (2 levels – inconsistent, consistent) – Consistent data sets contained event data that either consistently supported or consistently didn't support the mission. Inconsistent data sets contained event data that approached or exceeded a 50% inconsistency level for a given role in a given MSEL file, i.e. the data dithered between supporting and not supporting the mission approximately 50% of the time.
- **Data Timeliness** (2 levels – not timely, timely) – In timely data sets, all event data necessary to make operational decisions were injected within the first 13 minutes of a given replication. Untimely data sets did not expose all data necessary for making the correct mission support decision until the last 2 minutes of a replication.
- **Data Relevancy (degree of extraneous data)** (2 levels – little or no extraneous data, 50% extraneous data) – Relevant data sets contained little or no extraneous data. Non-relevant data sets contained extraneous data at an approximate 50% level.
- **Warfighter Roles** (6 levels – METOC, Blue Force Tracking (BFT), Target, Strike Asset, Support Asset, and Battle Damage Assessment (BDA)) – To control for potential effects that could arise from differences in individual warfighter roles, these roles were included as independent factors.

To conduct our experiment as a full factorial experiment either 48 distinct factor level combinations (2 x 2 x 2 x 6 = 48) or eight independent MSEL sets (6 roles for each MSEL x 8 MSELs = 48) would have been required. Due to time and resource constraints, only *four* independent MSEL sets were developed and utilized during experimentation, which resulted in 24 potential, distinct combinations of the independent factor levels defined above. The drawback of this limited number of combinations was it was impossible to estimate all of the interaction effects; therefore, a subset of possible factor/level combinations was chosen based on the effects with the highest likelihood of having a significant impact on the responses. In addition, that subset was chosen so that the number of desired estimated effects didn't exceed the total number of effects that could be independently estimated with the available amount of data in the experiment (see Table 1).

Based on these constraints and the factor interactions that were deemed most important, the effects that were estimated are shown in blue in Table 1. The design matrix reflecting these choices was produced using the Statistical Analysis Software (SAS) JMP® and is shown in Table 2. To average out any "learning" effects, each MSEL was executed three times, rotating individual warfighter role player assignments for each "replication".

2.6 Data Collection

Several data collection methods were used to support our experimentation effort. Decision-related data and role player comments were automatically captured via the EWM and its instrumented interface to the GOC-CE. Text chat was captured via the use of the IWS collaboration tool. The status of event data injects by the MIA tool was captured via the automated logging capability provided by that tool. And finally, human factors data, e.g. mental demand, temporal demand and

frustration level, were captured via the use of a Likert scale-based survey administered to all role players at the end of each experimental replication.

Table 1. Degrees of Freedom (df) and Two-Way Interactions

Factor	Degrees of Freedom (df)
Data Timeliness (Time)	1
Data Extraneous (Extra)	1
Data Consistency (Cons)	1
Role	5
Time*Cons	1
Extra*Cons	1
Time*Extra	1
Role*Time	5
Role*Cons	5
Role*Extra	5
Role*Cons*Extra	5
Role*Cons*Time	5
Role*Extra*Time	5
Cons*Extra*Time	1
Role*Extra*Time*Cons	5
Total df available from 4 distinct MSELs	23

21

This number can't be bigger than this number

Table 2. Design Matrix for Experiment

Consistency	Relevancy (Absence of Extraneous Content)	Timeliness	Role	MSEL File #
CONSISTENT	NO EXTRA	TIMELY	METOC	4
NOT CONSISTENT	NO EXTRA	NOT TIMELY	BFT	4
NOT CONSISTENT	EXTRA	NOT TIMELY	TARGET	4
NOT CONSISTENT	EXTRA	TIMELY	STRIKE	4
NOT CONSISTENT	EXTRA	NOT TIMELY	SUPPORT	4
CONSISTENT	NO EXTRA	TIMELY	BDA	4
NOT CONSISTENT	EXTRA	NOT TIMELY	METOC	3
CONSISTENT	NO EXTRA	TIMELY	BFT	3
CONSISTENT	EXTRA	TIMELY	TARGET	3
CONSISTENT	NO EXTRA	NOT TIMELY	STRIKE	3
CONSISTENT	NO EXTRA	NOT TIMELY	SUPPORT	3
NOT CONSISTENT	EXTRA	TIMELY	BDA	3
CONSISTENT	EXTRA	NOT TIMELY	METOC	2
CONSISTENT	EXTRA	NOT TIMELY	BFT	2
NOT CONSISTENT	NO EXTRA	TIMELY	TARGET	2
NOT CONSISTENT	NO EXTRA	NOT	STRIKE	2

		TIMELY		
CONSISTENT	NO EXTRA	TIMELY	SUPPORT	2
CONSISTENT	NO EXTRA	NOT TIMELY	BDA	2
NOT CONSISTENT	NO EXTRA	TIMELY	METOC	1
NOT CONSISTENT	EXTRA	TIMELY	BFT	1
CONSISTENT	NO EXTRA	NOT TIMELY	TARGET	1
CONSISTENT	EXTRA	TIMELY	STRIKE	1
NOT CONSISTENT	EXTRA	TIMELY	SUPPORT	1
NOT CONSISTENT	EXTRA	NOT TIMELY	BDA	1

2.7 Data Analysis

There were five main response (dependent) variables analyzed, along with a list of human factors survey responses. The goal of our analysis was to identify significant predictive relationships between the explanatory (independent) variables and the responses. These five main responses were:

- Data Quality HALFEX
- Data Quality ENDEX
- Data Mission Support HALFEX
- Data Mission Support ENDEX
- Delta Data Mission Support

These variables are all discrete (categorical) variables. While ordinary regression models assume a normal distribution for *continuous* response variables, our analysis however assumed binomial, multinomial or Poisson response distributions because of their categorical characterization. Our analysis also took into account whether the response (and explanatory) variables were ordinal.

The Data Quality HALFEX, Data Quality ENDEX, and Delta Data Mission Support were tertiary, ordinal variables, which implied multinomial distributions. The analysis for them employed extended logistic regression techniques, namely the proportional-odds cumulative logit model. Data Mission Support HALFEX and Data Mission Support ENDEX were binomial variables, which implied a binomial distribution. Standard logistic regression techniques were used for the analysis of these variables.

Finally, participant responses from the human factors surveys were all based on a five-point Likert scale, and therefore were assumed to have multinomial distributions, which were analyzed with the proportional-odds cumulative logit model, as above. However, since there were additional levels of response, we also used gamma statistics to ascertain if there was evidence of monotone trends (i.e., concordant pairs of levels of explanatory and response variables) between these responses and the ordinal factors (data timeliness, data relevancy, data consistency).

3. RESULTS

The factor that contributed most significantly to the quality of the mission support decision was data consistency. Quality in this case, refers to the ability to make a correct decision. The relationship between data consistency and the mission support decision variable was found to be statistically significant at a .98 or higher probability level such that as data consistency increased so did the ability to make a correct mission support decision. That relationship was true when measured at both the halfway point and at the end point of all experimental replications (Figure 8). Data relevancy, i.e. the degree of extraneous data, and data timeliness were shown to not have a statistically significant relationship with the mission support decision variable at either the halfway or end points of the experimental replications (Figures 9 and 10, respectively).

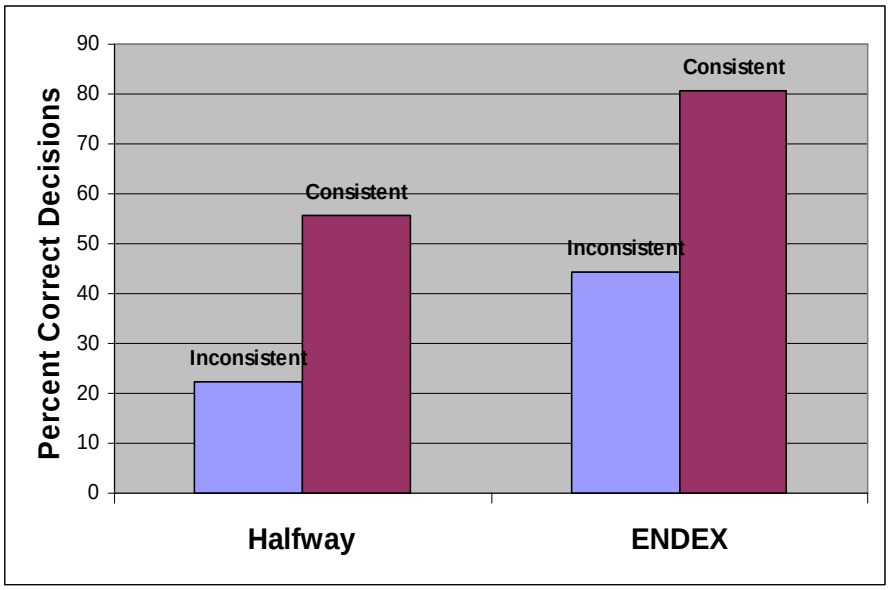


Figure 8. Relationship of Data Consistency to the quality of the Mission Support Decision

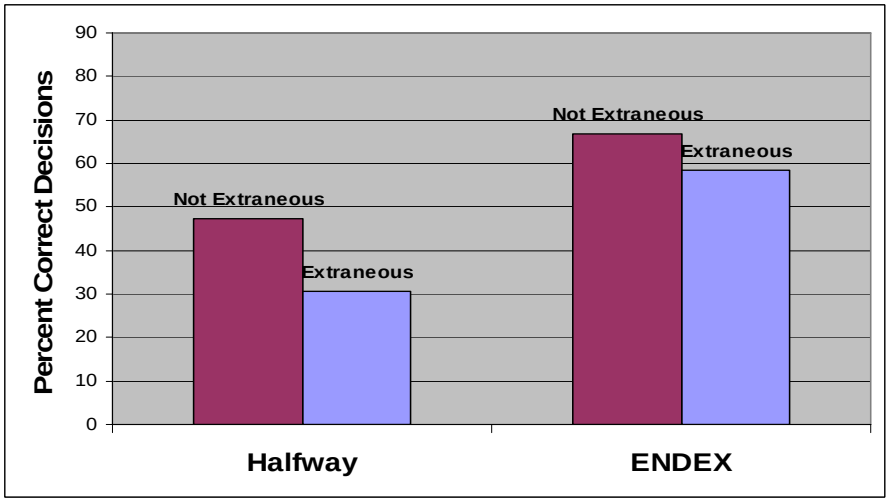


Figure 9. Relationship of Data Relevancy to the quality of the Mission Support Decision

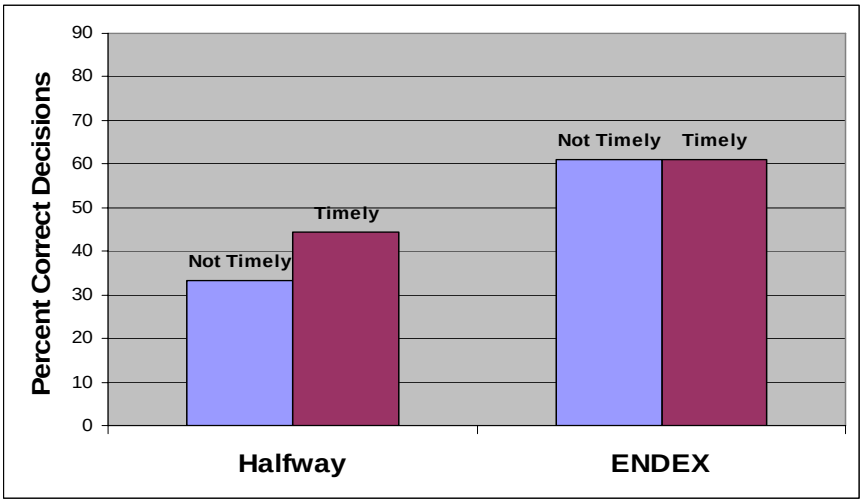


Figure 10. Relationship of Data Timeliness to the quality of the Mission Support Decision

Other secondary factor interactions were also evaluated and, with one exception, shown to not have a statistically significant relationship with the quality of the mission support decision. That exception was data consistency in combination with data timeliness, which was shown to be statistically related, in a positive way, to the mission support decision variable at the .98 or higher probability level.

These findings were further corroborated by the results of human factors data analysis. Figure 11 shows that data consistency alone and in concert with data timeliness had a statistically significant negative relationship with Mental Demand, Temporal Demand, and Frustration Level in that increased levels of each of those factors was shown to be correlated with a decrease in data consistency level.

Response	Significant Factors	Probability Value	Explanation
Mental Demand	Consistency	0.991	Mental Demand increased significantly with inconsistent data
Physical Demand	None	N/A	Physical Demand didn't differ significantly over factor levels
Temporal Demand	Consistency	0.981	Significantly higher time stress with inconsistent data
Performance	None	N/A	Participants' perceived performance same across all factor levels
Frustration Level	Time, Cons*Time	0.959 0.937	Participants significantly more frustrated with untimely data and when data is both untimely and inconsistent
Situational Understanding	None	N/A	Quantity of data understood didn't differ significantly over factor levels
Situational Understanding - Evaluation	None	N/A	Ability to evaluate data didn't differ significantly over factor levels

Figure 11. Relationship between Data Consistency and Mental Demand, Temporal Demand and Frustration Level

4. CONCLUSIONS

Based on the results of our FY07 experimentation, we were able to successfully achieve our stated objectives. We demonstrated that the executable workflow model (EWM) with its

instrumented interface to the GOC-CE was an effective means for visualizing mission workflow status and for automatically collecting data to support post experimentation analysis and reporting. That capability provided a means for collecting, analyzing, and evaluating data needed to test our decision-based hypothesis. We were able to successfully generate scenario-based event data, vary the levels of consistency, relevancy, and timeliness of that data based on an experimental design, and automatically inject that data as decision-making stimuli for participating role players into our experimental environment. We were able to demonstrate that our evaluation framework successfully supported hypothesis testing and as such, we were able to show, within the limits of our experimental environment, that data consistency alone had a statistically significant relationship with decision quality as measured by the ability to make a correct mission support decision.

Although a good beginning, the intended objective for our overall evaluation framework and specifically for the EWM is to be able to evaluate a portfolio of capabilities that supports a mission area such as Global Strike. Such a portfolio could contain, for example, advanced data fusion, collaboration, and visualization services, which claim to provide operational advantage to mission area warfighters. Through the use of the EWM, which must be adaptable and capable of agile modification in response to a changing net-centric environment, a quantitative assessment could be made to determine the contribution of each service in reducing the overall time required to complete the mission workflow and/or increase the quality of mission related products. That objective is the focus of our C2 evaluation research for FY08.

5. REFERENCES

1. Forsythe, S.L., North, P.D., and Barnes, V.B, "Evaluation of Net-centric Command and Control via a Multi-resolution Modeling Evaluation Framework," in *10th Int. Command and Control Research and Technology Proc*., June 2005

2. North, P.D., Forsythe, S.L., "Evaluating Net-centric Command and Control via a Multi-resolution Modeling Evaluation Framework: a FY05 IR&D Project" in *11th Int. Command and Control Research and Technology Proc*., June 2006

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Appendix A. Multi-resolution Modeling Evaluation Framework

A significant challenge to evaluating net-centric C2 is to develop an approach that facilitates evaluation of C2 capabilities in a complex hybrid architecture environment. Our approach, referred to as the Multi-resolution Modeling Evaluation Framework (MRMEF), uses constructive, virtual, and live simulations and hardware-, software-, and humans-in-the-loop where appropriate. Multi-resolution Modeling (MRM) has many advantages that are needed to analyze C2. MRM has been successful because it has the characteristics needed to solve difficult analysis problems by integrating information achieved with high-fidelity models and generalizing the results and implications via a low-resolution model (Reference 3). An overview of the MRMEF is shown in Figure A-1.

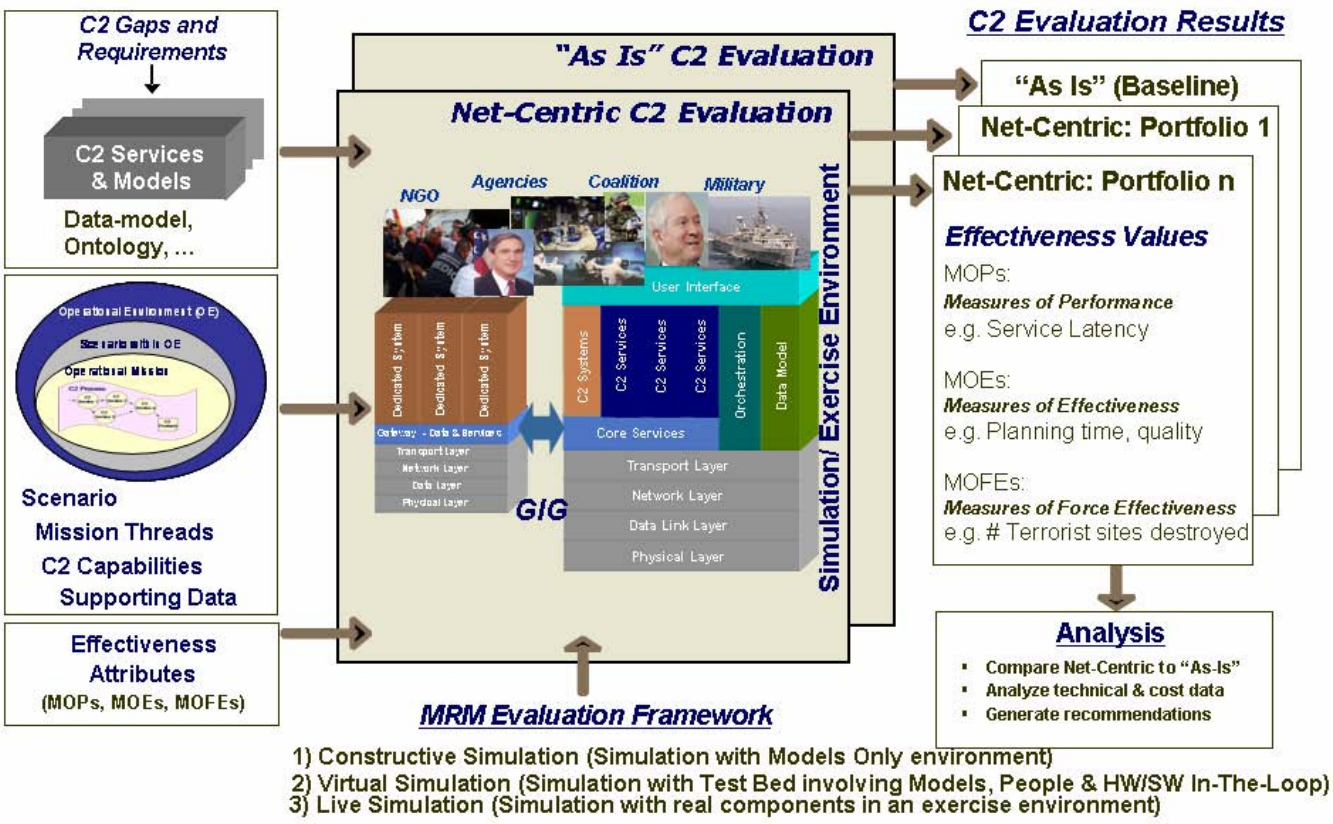

Figure A-1. Multi-resolution Modeling Evaluation Framework

The simulation/exercise environment of the MRMEF contains the entire hardware and software infrastructure needed to support the constructive, virtual, and live simulations of the framework.

The "cube" portion of the diagram represents real or modeled C2 or C2-related components. Inputs to the framework consist of a set of C2 services to be evaluated; the services were derived from C2 gap analysis, C2 requirements definition, data modeling, and so forth. A scenario defines the operational mission, i.e., the problem to be solved, and serves as the contextual basis

for the evaluation. Measures to assess performance and effectiveness are defined based on the context of the scenario. Evaluation of C2 capabilities is accomplished by executing the “cube” components, (real, simulated, or a combination of real and simulated) in the context of the appropriate MRMEF simulation/exercise environment. C2 evaluation results are generated as a result of executing the scenario.

An “as-is” evaluation is accomplished by developing a scenario-based model of the “as-is” process to be evaluated and executing that model as a constructive simulation within the framework. A second model is developed representing the net-centric equivalent of that process. The net-centric process, which may involve a hybrid of legacy and net-centric components, both real and simulated, is executed within the framework as a virtual simulation. When real components are used, they are interfaced with the simulation via a separate test bed, which allows the real components to interact as necessary with modeled components. The resulting simulation executes at a higher level of fidelity or resolution overall. The framework also encompasses a very high-fidelity live simulation executed outside the laboratory environment with real players and components.

Analysis consists of comparing the “net-centric” with the “as-is” results and analyzing the differences to determine, both qualitatively and quantitatively, whether the application of net-centric principles and components to an existing process has enhanced or degraded engineering, command and control, or mission-level performance as measured via MoPs, MoEs, and MoFEs, respectively. If cost information about deploying and maintaining net-centric C2 capabilities is available or estimated, those data can be combined with the technical evaluation results to help guide future architecture, acquisition, and deployment decisions.