C4I Tactical Applications Utilizing Embedded Simulations

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Abstract

Embedded simulation technologies have matured suitably to allow C4I systems to incorporate simulations within their design. Simulation based mission applications such as a course of action analysis application, or visual representations of complicated operational assessment models, can significantly improve the quality and timeliness of tactical decisions for military operations. Simulation based applications have the ability to process C4I data beyond human cognition, and display it in an intuitive and meaningful way for key tactical decision makers.

This paper reports progress on the Navy's Embedded Simulation Infrastructure (ESI) Program implementation and management of embedded models and simulations for C4I systems that are compliant with the Defense Information Infrastructure Common Operating Environment (DII COE). The ESI Program provides a robust set of common reusable DII COE simulation services and object-oriented links between simulations and DII COE services and data bases. The development of two Global Command and Control System (Maritime) Mission Applications utilizing this technology are discussed: the Planning Mission Editor and the Weapons of Mass Destruction Analysis Application.

1. Background

Command, Control, Communications, Computers and Intelligence (C4I) systems have evolved from their inception as essentially electronic "maps" displaying geographical position of known units and platforms ("tracks"). This geospatial integration of information into a map format is a natural, intuitive way for decision makers to see a summary of information with the all important element of force disposition preserved in the display.

Alternate methods of integrating information other than traditional "tracks" (force positions over time) into a "Common Operational Picture" is possible by utilizing embedded models or simulations to present synthetic views of that information. These adaptive views can enable cogent situational awareness of information beyond human cognition in that data's raw state.

An example could be an embedded electromagnetic propagation simulation that processes electronic sensor performances, atmospheric conditions, and terrain features, to produce a three dimensional picture of sensor coverage around own forces. While these types of enhanced information processing have been available in stand-alone computer systems, their tactical use is limited due to the lack of integration with the C4I system.

These basic requirements for enhanced information processing in C4I dictate the development of processes for the use of embedded simulations within tactical applications.

2. Defense Information Infrastructure Common Operating Environment

The Defense Information Infrastructure Common Operating Environment (DII COE) [1] is the framework upon which many modern U.S C4I systems are developed. Systems such as the Global Command and Control System (GCCS), the Navy Maritime Version (GCCS-M), the Army Global Command and Control System (AGCCS), and the Air Force Theater Battle Management Core Systems (TBMCS) rely on the DII COE to provide a robust set of common services and facilitate interoperability among those service systems.

These C4I systems also have the advantages of generally spanning the C4I hierarchy from sensor processing to key decision makers, and have access to many different types of databases and inputs from multiple C4I systems. This wealth of information available in C4I systems makes them ideal hosts for advanced tactical mission applications.

Many of the functions required by simulation based tactical applications already exist within the DII COE. However, the wealth of connectivity and software available within modern C4I architectures has not been effectively utilized for the development of embedded simulations in the DII COE architecture.

The complex and legacy nature of the DII COE, and the fundamentally different way C4I handles data and time issues, have made it difficult for use by the simulation development community. C4I applications were not originally designed using simulations and lack proper links that allow simulated data to be easily inserted into C4I without disrupting normal operations. It is however, the most direct path to the primary tactical user.

The Embedded Simulation Infrastructure (ESI) Development Program was initiated in FY 2000 to remove the barriers between DII COE and simulations. It is managed and funded by the Navy Modeling and Simulation Office (NAVMSMO) with the development performed by the Naval Research Laboratory (NRL).

3. The ESI Concept

The purpose of the Embedded Simulation Infrastructure (ESI) Program is to establish means of combining powerful embedded computer simulations with existing C4I functionality and produce enhanced C4I tactical applications.

3.1 Legacy Interfaces

A typical interface between an external simulation and C4I system is shown in the bottom frame of Figure 1. Messages are constructed within the simulations to be identical to the message formats of the specific C4I system. In essence, the simulation mimics another C4I system.

This interface approach views a C4I system as a "black box" and makes a tacit assumption that legacy C4I systems cannot be modified to accommodate the input of simulated data other than native messages. The advantage is that it provides a simulation interface without requiring changes to the C4I system.

For many applications though, there are severe limitations to relying on messages to pass simulated data. First, this approach is constrained to the limited sets of data supported by native C4I message formats. Second, the interface generally consists of one-way stimulation of the C4I system. Third, the C4I systems generally cannot function on an operational C4I network, but run off-line.

3.2 C4I Federates within HLA Federations

An evolution toward more robust interoperability has been achieved by integrating the High Level Architecture (HLA) within a DII COE compliant C4I system. The approach, shown in the middle frame of Figure 1, allows the C4I system to be a participant (i.e., federate) within an HLA Federation.

This interoperability method provides a simulation access to internal C4I functions and data not reachable by messages, such as the ability to interface with specific workstations within an operational LAN. This removes some of

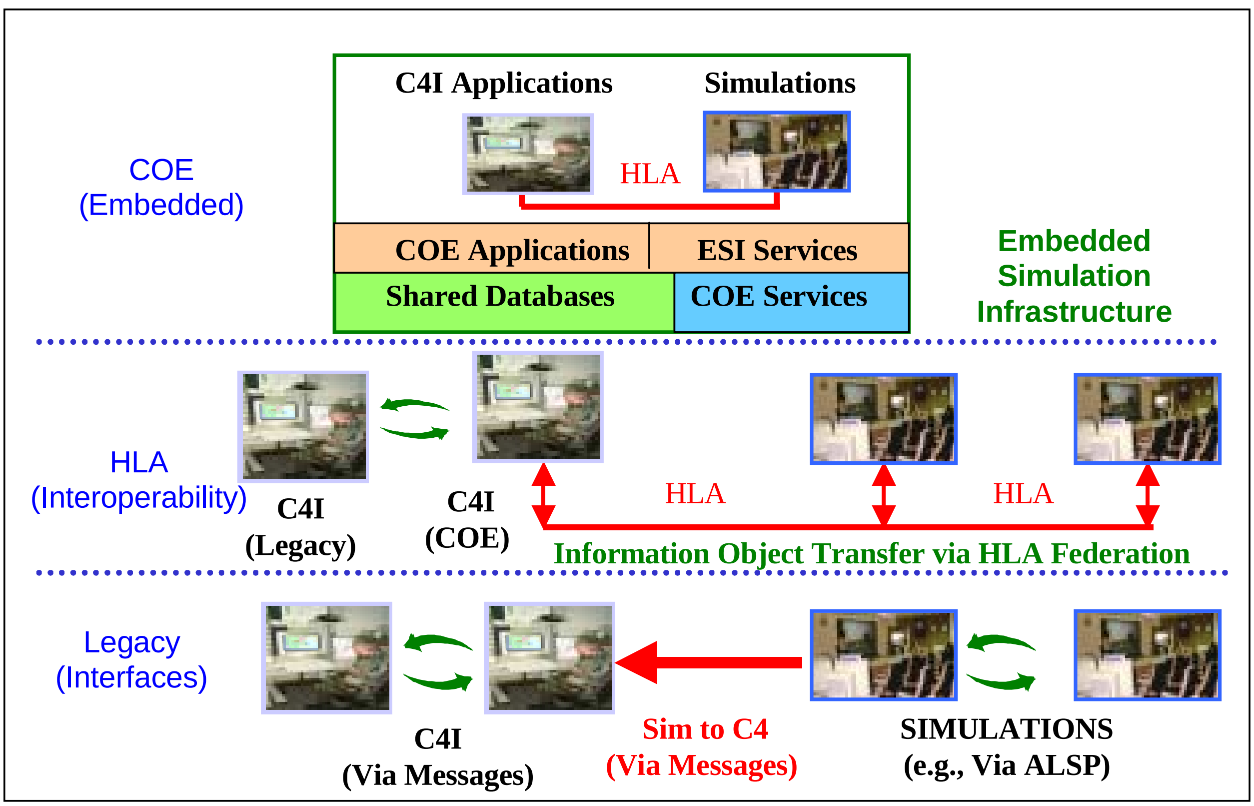

Figure 1
Migration from Legacy Interfaces to Embedded Simulations

the restrictions that the use of standard military message interfaces imposes. It provides a means to link C4I applications to large external simulations or federations for specialized purposes such as training or analysis. [2]

Initial C4I Federation development was performed by NRL for the Synthetic Theater of War (STOW) 97/98 Exercises where C4I/Simulation interoperability was considered a major achievements. More recently, GCCS and GCCS/M Federates have been established with the Joint Theater Level Simulation (JTLS), Navy Simulation System (NSS), Pegasus Federations and the ITEM simulation.

These Federations have provided selected simulations means to insert and display simulated forces in the GCCS Common Operating Picture (COP), to receive orders from the C4I system, and during the Navy GLOBAL 01 Exercise an ability to export the GCCS COP picture real-time to the NSS Simulation.

3.3 Embedded Simulations

The third and final evolutionary step toward C4I embedding simulations is shown in the top frame of Figure 1. The ESI program has developed simulation services and object oriented interfaces between the DII COE C4I architecture and embedded simulations within C4I applications. This allows C4I to harness the power of simulations in self contained applications. [3]

3.4 The DII COE Architecture

The DII COE provides a configuration managed software environment for C4I systems to draw upon in developing tailored applications. By creating an environment in which different C4I systems utilize common components (such as map displays, message processors, etc.) redundancies between different C4I systems are eliminated and interoperability between systems is improved. [1]

Figure 2 shows the categories of the main elements of a DII COE based C4I system. At the top layer, the C4I system specific Mission Applications will tend to maintain functionality that is not widely used by other applications.

The DII COE segments are organized into the Kernel, Infrastructure Services and Common Support Applications. They include such general services as: message processing, office automation, data access services, and security as well as more C4I specific applications such as: map servers, force track management, communications, message generation, and tactical decision aids.

4. The need for Simulation based C4I Tactical Applications

Forward looking concepts for C4I system use in modern information intensive warfare (e.g., Navy Network-Centric Warfare, the Air Force concept for Predictive Battlespace Awareness etc.) rely on accurate, timely access to C4I information and data. [4] [5] [6]

They also have an implicit requirement for sophisticated processing of that information and data for situational awareness, decision support, and operational control. When that information or data is beyond human cognition in its raw state, a model or simulation is required to transform that data into information useful to a commander.

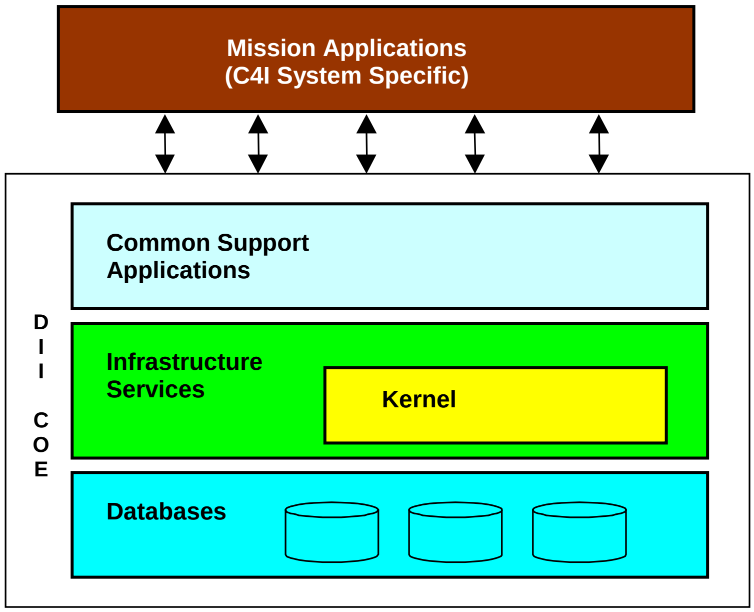

Figure 2
The DII COE Architecture

4.1 Situational Awareness

Very often C4I systems are looked upon as electronic maps, capable of displaying only platforms, units and contacts in a time/geographical position "map" paradigm. An "Operational Picture" has historically been an animated map.

However, DII COE linkages to new information databases compel the development of equally new methods to process and display information beyond mere positions of "tracks".

For example, logistic information from various world wide logistics databases is linked in a "drilldown" fashion in the new Global Combat Support System (GCSS). GCSS is a DII COE Mission Application integrated into the GCCS.

Similarly, the GCCS Integrated Intelligence and Imagery (I3) application links sites and tracks on the map to intelligence and imagery databases. These types of geographically oriented displays of relevant fused information enhance the commander's situational awareness by both the human factor of their display and the ease of information retrieval. Situational awareness beyond this indexing and organization of information into sets of data specific to a geographic location is the next step: "Adaptive C4I Operational Domains".

4.2 Adaptable C4I Operational Domains

Current C4I applications emphasize the display of supplementary data as indexed information tied to a track or site within a "Common Operational Picture". Little has been done to process or interpret data in regards to a specific mission support element that reflects the planning, assessment and control needs of individuals within the military organization.

One needs to look beyond the paradigm of the electronic map and think about the integration of useful information in an operational picture representing something other than troop geo-locations over time. There seems to be a need to analyze different facets of an operational situation or plan.

These other "operational domain" facets could include a superposition over a 2-D map of a schematic diagram of communications networks between sites and their current and projected operational loading. This would assist in both operational control of that network, and in situational awareness of the commander to his/her underlying command structure vulnerability due to network loading.

Decisions could be supported by this "Communications Operational Picture" prompting the commander to problems, and alternative network routing or loading schemes to reduce his/her vulnerabilities.

Similarly, a 3-D geospatial view of the radar electromagnetic space surrounding the battle group, with platforms, sensors, terrain, and atmospheric conditions provided from the C4I system, would provide the commander valuable insight for force defense.

A broader "Electromagnetic Operational Picture" could provide situational awareness of own force vulnerabilities (i.e., detection versus counter detection for various Emission Control conditions, jamming effectiveness, etc.) to support decisions in strike planning against enemy targets and protection from hostile force activities.

Other adaptive operational domains could include: the Acoustic domain, the Weapons of Mass Destruction Defense domain, the Information Operations domain, the Logistics domain, etc. In all these cases an embedded simulation is at the core to produce information relevant to these domains from raw C4I data and provide the resulting situational awareness and decision support.

4.3 Decision Support Requirements

Key element of tactical decision support in C4I is timeliness and access to tactical information. Deliberative planning and analysis may not require real time access to C4I information or need to integrate with other C4I applications. However, in order for decision support to serve the commander in tactical situations, timeliness requires a close coupling with the C4I data.

Tactical decision support can have many different flavors, from "what if" types of course-of-action analysis, to a commander's inference from the insight of good situational awareness. Simulation based applications have traditionally been used in decision support in a "what if" war-gaming type of analysis. While this can be operationally useful, it is also subject to debate on validity of results.

Embedding a simulation capability within a C4I application can help with the timeliness and tactical relevance but not with the validation of subjective results. Far more fertile for rapid adoption in C4I systems are deterministic models or simulations that can produce unambiguous results.

Adaptable C4I Operational Domains, utilizing deterministic simulations, will provide the commander valuable insight and information for decision based upon validated results. For instance; a C4I application (based on a well validated simulation) that produces a time projected representation of a potential chemical contamination "cloud" and inserts it into the Common Operational Picture to interact with force positions and planned movements. This would be immediately tactically useful for force protection, operations planning, and maneuver control.

Such an application is the GCCS/M Weapons of Mass Destruction and Analysis (WMDA) Mission Application under development. It utilizes the DII COE Embedded Simulation Architecture discussed in the following sections.

5. ESI Program Overview

The Embedded Simulation Infrastructure (ESI) Program applies new technologies and a bold architectural approach to the challenging problem of integrating simulations within C4I.

5.1 Program Objectives

The overall purpose of the ESI program is to establish a simulation-friendly software environment that facilitates the design of complex simulation-based mission applications within C4I systems. This program will demonstrate the feasibility of combining existing DII COE functionality with computer simulations by implementing the following three objectives:

- **Objective 1:** Provide capabilities to link simulations with existing DII COE services and C4I mission applications.
- **Objective 2:** Identify and develop a set of Modeling and Simulation (M&S) services commonly required by mission-oriented simulations.
- **Objective 3:** Develop simulation-based mission applications for situational awareness and decision support.

5.2 The ESI Design

A block diagram of the embedded simulation architecture in the DII COE is shown in Figure 3. The example in the upper right is the Weapons of Mass Destruction Analysis (WMDA) Mission Application. It incorporates the common, reusable modeling and simulation (M&S) services within its design.

The basic ESI Services (Force Generation, Simulation Display, and Time Management, etc.) are envisioned as eventually migrating to the DII COE and are displayed in the DII COE Common Support Applications layer as Modeling and Simulation (M&S) Services. The arrows represent links that can pass simulated data to DII COE Services and Support Applications, other C4I Mission Applications and C4I databases.

A simulation-based application is treated like any other application within the C4I system utilizing the ESI. By comparing Figure 3 with Figure 2 it is seen that the Embedded Simulation Infrastructure architecture is identical with the DII COE architecture but adds additional services and interfaces. The design was intentionally made consistent to enhance commonality and functional reuse, which are DII COE design principles.

6. DII COE Services and Simulation based Mission Applications

Interoperability links are required between embedded simulations and C4I applications. For example; links will be provided to interface simulations to: Map Services, Data Fusion, Track Correlation, Track Management, Communications Modules, Network Services, Alerts, Presentation and Web tools, Distributed Computing Services, and Data Base Management Systems.

Some DII COE services accessed by a simulation do not require simulated data to be passed and can be readily incorporated within simulations with no special provisions. For example; a simulation could call on Operating System, office automation or network services with no extraordinary interface requirements. The simulation could access these services with standard application program interfaces (API).

Other applications will require substituting simulated data with real world data. Services such as track management, map services and data fusion are more complicated and require special methods to process simulated data within C4I.

6.1 Managing simulated data in C4I

The use, distribution, safeguards, and identification of simulated data within an operational C4I system has been the subject of research and study. For the purposes of this discussion, simulated data refers to data similar to actual C4I

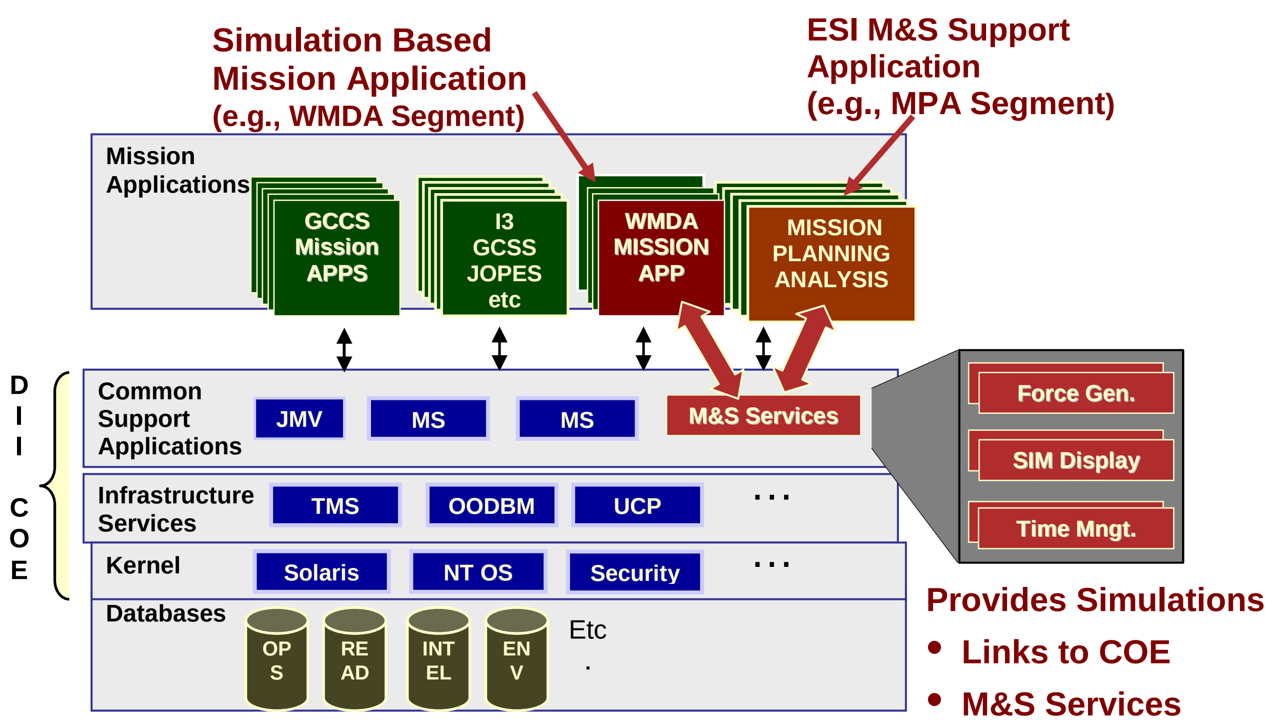

Figure 3
GCCS Embedded Simulation Architecture

data; but produced by a simulation. It could also be real C4I data with a non-real-time base (e.g., archived data). In any event, the challenges of managing this data and presenting it to the user are the same.

The introduction of simulated data presents problems for the operator and C4I system in both the perception of the simulated data vis-à-vis real world data, and its interaction or relevance with data of a real nature or differing time base. This simulated data requires special handling and presentation in order to maintain cognitive linkage to, but distinction from, the current real world situation.

Methods and software incorporated in the NRL developed Embedded Training applications already within GCCS and GCCS/M have been used to routinely insert simulated data into operational C4I. These functions and interface links have been adapted and expanded to operate with embedded simulations.

6.2 Operating Faster/Slower than Real-Time

The C4I system must accommodate a simulation or model that operates in a time base different from the C4I systems real-time. This leads to a requirement for the C4I system to be time agile and dynamically adjust it's time reference to the changing time base of a simulation running at faster or slower than real-time. This dynamic time reference shift from real-time is necessary for a simulation to do an operationally significant job. Some examples are:

- Projecting operations into the future for planning purposes or analyzing potential courses of action.
- Adaptive Operational Domains that influence the tactical situation. (e.g.: radar coverage, acoustic conditions, WMD effects, Information Operations etc.) These may require the simulation to operate faster or slower than real-time.
- A combination of both such as simulating a WMD event and time projections in the future to plan evasive action.

Obviously, a mechanism must be available in the C4I system to handle this dynamic time base, and to cue the user as to which time base is in effect.

6.3 Protecting Normal Operations

When operating a simulation within an operational C4I system, the entire system must be protected from the inadvertent corruption of real-world operational data.

This new capability must be integrated into the operational system. This will give the application and its simulation access to all the C4I system's data and connectivity, and allows meaningful interaction with decision makers.

In order to use simulated data within an operational C4I network, a system to safeguard and "quarantine" the simulated data must be devised. The absence of such a C4I COE feature has limited operational use and confidence with simulation activity on "live" C4I networks.

Again, by building on past experience with these issues in the development and fielding of non-real-time C4I applications, NRL has developed methods for safely inserting some classes of simulated data into operational C4I systems. However, an expansion of these methods will be required.

7. ESI Modeling and Simulation (M&S) Services

Some of the most burdensome tasks within simulations are the provision of: display and mapping services, simulated force generation/maneuvering, and time and data base management services. Several of these major embedded simulation services are described.

7.1 Simulated Force Generation

Simulations used in tactical decision aids, operation planning, and course of action (COA) analysis are often based on executing simulated scenarios that provide insight to the tactical decision maker. A key, yet burdensome development required is the software to create and manipulate scenarios, and interface these with existing C4I analysis applications.

An ESI design goal is to provide a standard means to generate, distribute, and manage simulated operational warfare scenarios and data within C4I without disrupting normal operations. A set of functional requirements for scenario initialization, maneuvering and playback are listed.

- Create & Manage Scenarios
  - ➢ US, Threat, & Others
  - ➢ Scripted & Free play
  - ➢ Distributed Control
- Provide Means to Store & Replay
  - ➢ Faster & Slower than real-time
- Integrate Operational Forces
  - ➢ Live, Virtual and Constructive
- Represent Physical Environments
  - ➢ Sea, Undersea, Air, Land, Space
- Attach Simulated Forces to Mission Applications
  - ➢ DII COE Services
  - ➢ Mission Applications
  - ➢ Technical Databases
- Use Common Data, Standardized Models
  - ➢ Object Oriented Interfaces
  - ➢ Messages (e.g., OTH Gold)

The Mission Editor Application in the suite of ESI services is designed to meet these basic requirements. It produces a time/position "ground truth" scenario and can display all track positions over time, with the means to: generate new tracks, modify any aspect of existing tracks, adjust and change the time base of the scenario, and store, replay, and modify any existing scenario.

7.2 Simulation Common Operational Picture Display

A principal function of a C4I system is to provide a Common Operational Picture (COP) to the tactical decision maker. The COP software is an embodiment of map services, communication services, data fusion, data management, and display of dynamic track reports that comprise the tactical situation. The COP also provides the tactical user's primary interface to the DII COE applications and is the reference point of nearly all C4I decision aids.

Applications containing simulated forces will require the same kind of map and force display services, but they must be capable of running simulated data in non-real-time. The ESI will provide a Simulation Common Operational Picture (SIM COP) that permits simulated forces to be displayed in the same manner as real-world forces but allow the time reference and time elapse ratio to change.

SIM COP will key the user to its non-real-time orientation, yet will maintain the familiarity and function of the familiar real-time C4I COP.

The SIM COP will provide a simulation full C4I access to insert simulated data in place of and complementing real-world data, and access to all the analytic capability afforded real-world operations. Extensions to the SIM COP will allow 3-D visualization of Adaptive Domains, while preserving the geospatial orientation of the COP. The ESI is on the leading edge of C4I technology in this area, and resulting requirements will be channeled into the DII COE development process.

7.3 Time Management

A major concern about the use of simulations in C4I applications is the issue of time management. However, it is less vexing than might be assumed. Under the DII COE most C4I applications and the systems themselves run independent of operating system time. This allows various time bases to coexist, as long as the situational awareness safeguards are in place to distinguish that time base. The SIM COP construct is one way to assure the operator of the time base of the information he/she is viewing.

In a properly designed mission application the simulation engine can operate at any time base/ratio required quite independent from the C4I system time base during normal operations. The key "devil in the details" is how that resultant information is displayed, and how the input information is processed and handled. The ESI SIM COP concept handles the former, and the Mission Editor application handles the input to the simulation.

8. Application Example: Weapons of Mass Destruction Analysis

M&S capabilities will be demonstrated within the Global Command and Control System (GCCS) in the development of a Tactical Mission Application that contains simulated scenario data and operates in non-real-time. The purpose of this application is to provide an additional tactical capability to the operating forces and to refine the requirements for continued development of the C4I-Simulation linkages and the simulation building blocks.

8.1 Overview of the WMDA Application

A Weapons of Mass Destruction Analysis (WMDA) tactical situational awareness and analysis application is under development. It utilizes a Chemical, Biological and Radiological (CBR) contamination cloud model to predict contamination intensity and dispersion over time. This model will obtain all it's force disposition (both own forces, and assumed hostile) data directly from the GCCS/M COP in real-time, as well as link to technical databases required through the COE.

This mission application will provide direct tactical mission support to the Battle Group staff. It will enable visualization of the complex effects of a contamination cloud based on type of delivery/dispersion, wind currents and projected atmospherics, terrain, and force evasive movement. It will be configurable to provide both planning and real-time situational assessments.

The ability to analyze operational plans (in non-real-time) developed by the Mission Editor Application will allow the analysis of evasive courses of action, based on own force disposition and intelligence reports of projected threats.

Figure 4 is a simplified architecture block diagram that shows how the WMDA application interacts with the DII COE, the Mission Editor application and the COP. In the real-time mode this application is driven by real world C4I common operational and intelligence data. In the situation assessment and planning mode the Mission Editor drives this application.

8.2 Real-time Mode

The WMDA application provides the tactical decision maker a real-time COP display of a real or projected Chemical, Biological, or Radiological (CBR) contamination cloud in the battle space. Based on a reported or assumed contamination delivery vehicle, it computes contamination distributions as a function of time and displays them visually as dynamic cloud track types.

This information can provide decision makers immediate notification of vulnerabilities to a reported CBR attack, help assess self defense capability, and predict the time and contamination levels of force exposure based on atmospherics and maneuver.

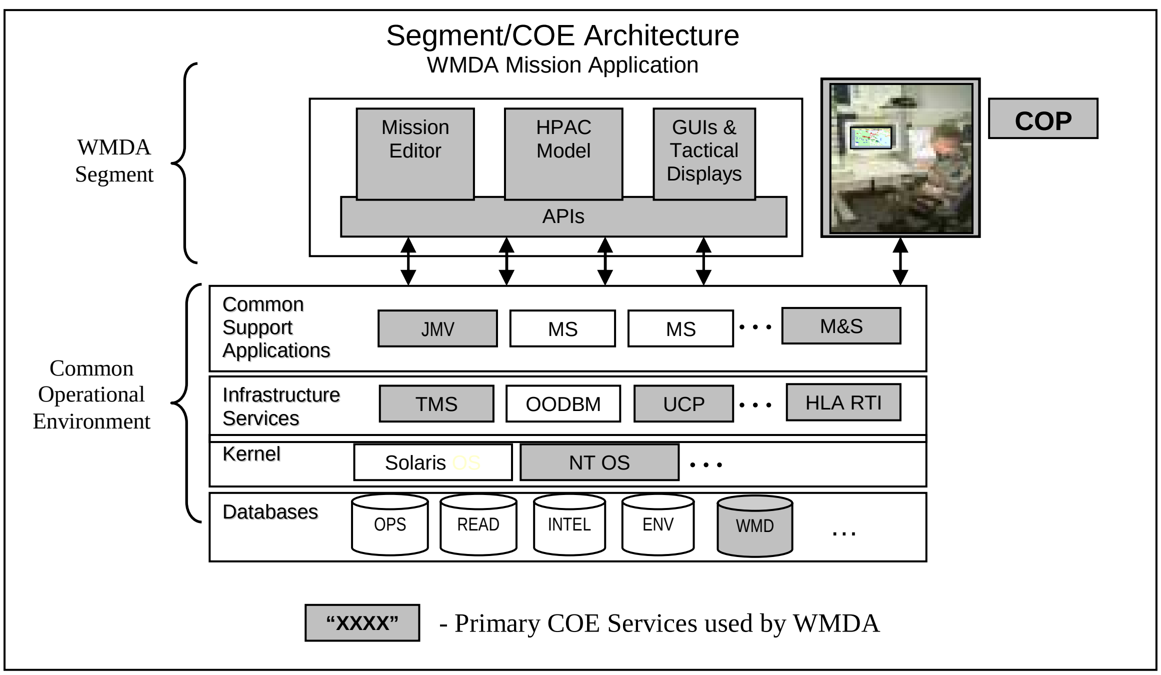

Figure 4
GCCS /M Weapons of Mass Destruction Analysis Application

The user is cued to the probability of contamination in those areas based on:

- The Battle Group platform positions, and intended movement.
- The opposing force CBR delivery vehicle position and type of delivery.
- The geographic terrain based on platform geographical position.
- The atmospheric conditions.

The utility of this mode of operation is that a Battle Group Commander can assess his/her force CBR vulnerabilities in real-time, as well as easily interpreting the expected consequences of planned evasive actions. This will enhance readiness as well as assist in tactical decisions, especially in the area of own force protection from a CBR attack.

8.3 Planning Mode

The WMDA application will also analyze operational plans produced by the Mission Editor in a non-real-time (i.e., time-projections or after-action analysis) mode.

The Commander will have the capability to step through an operational plan, and assess the CBR vulnerabilities of his/her forces during the planned operation based on intelligence information or what-if analysis for worst case projection. This capability will add much needed CBR defense analysis input to operational planning, as well as allow consideration of effects currently too complex or time consuming to analyze by manual means.

8.4 Mission Editor Application

The Mission Editor shown in the upper left of Figure 4 provides the Command Staff Planner a means to easily create operational planning scenarios to assess for force vulnerabilities using the WMDA application. The Mission Editor is a fundamental M&S application used as the backbone for a series of situation assessment and decision support C4I applications such as the WMDA.

The Mission Editor is fully integrated with the DII COE. It allows other GCCS and GCCS/M applications to access the planning scenarios and data through DII COE databases.

9. Summary

The Embedded Simulation Infrastructure will facilitate Mission Applications to incorporate embedded simulations by providing links to DII COE system services, other C4I applications, and C4I databases A set of common simulation services are being developed that can be incorporated into the simulations for ease of development and integration into C4I systems.

The ESI will insulate the simulation/C4I developer from having to solve the issues of C4I force generation, simulation display, and time management in the DII COE. It will provide a well documented and proven set of COE services to accomplish those tasks.

The ESI program began in FY 00. Some of these services have been developed; others are under development or at the conceptual phase. The expected completion date of the initial WMDA Application is early FY 03 and a useable Embedded Simulation Infrastructure is scheduled for FY 03. A released version should be available in FY 04.

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