New Navy Solutions: Developing Simulation Based C4I Applications

Gene Layman, Ph.D.
Naval Research Laboratory
4555 Overlook Ave. S.W.
Washington, DC 20375
layman@nrl.navy.mil
(202) 767-6873

Jim Weatherly
Navy Modeling and Simulation Management Office
2000 Navy Pentagon PT 5486
Washington, DC 20350-2000
Weatherly.Jim@HQ.NAVY.MIL
(703) 604-7807

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ABSTRACT: Simulation based Mission Applications are difficult to develop due to the conflicting nature of current Command, Control, Communications, Computer and Intelligence (C4I) systems and simulations. C4I systems process real world data to produce a common operational picture as accurate and as close to real time as possible. Simulations process simulated data, operate in variable time bases and present alternate courses of action, plans, analytical results, etc. C4I systems have made few provisions for these types of processes.

The Navy's Embedded Simulation Infrastructure (ESI) Program was undertaken to provide Modeling and Simulation (M&S) software components to be used as building blocks for simulation based mission applications within C4I systems that are compliant with the Department of Defense's Common Operating Environment (COE). Standard software components have been developed to link simulations to internal COE and C4I functions and to manage simulated data and variable time bases in C4I systems. A variety of sharable M&S software components are available to generate planning and training scenarios, provide simulations links to internal C4I data bases and functions, manage the simulated data within the C4I system, manage variable time bases, display simulated data, integrate simulations with other applications and perform communication tasks.

The provision of an architectural framework within the targeted environment and sharable modeling and simulation (M&S) software components that are common, but difficult to develop, permits the design of tactical C4I applications without the requirement of becoming C4I system experts. The M&S services have been used in the development of more than a half dozen applications within C4I systems such as the Global Command and Control System (GCCS). Examples include the GCCS-Maritime C4I Team Trainer System (CTTS), the Range Fusion System (RFS), the Weapons of Mass Destruction Defense (WMDD) Application and several others described in this paper.

1. C4I Limitations

Command and Control is a continuous, cyclical process by which a commander makes decisions and exercises authority over subordinate commanders in accomplishing an assigned mission. [1] The Command and Control decision and execution model is a continuum that begins with "observe" followed by "orient", "decide" and "act" and then back to "observe" the results of these decisions and actions and repeat the cycle.

The primary product of current operational C4I systems is a common operational picture (COP) used by decision makers to assess a tactical situation. The COP is an electronic map which displays the terrain, military structures, locations and movements of the forces, etc. The COP also provides amplifying information about the objects and events as they occur.

The COP supports the "observe" and "orient" phases of the decision cycle quite well. However, C4I lacks adequate support for other command and control phases "decide" (plan operations) and "act" (control operations).

As C4I developers, we have focused primarily on the COP fusion problem and designed the systems for this single purpose. C4I systems acquire information from a variety of sensor inputs and observations. Data is processed hierarchically through multiple levels of fusion to achieve a Common Operational Picture which is broadcast to the world wide network of C4I systems.

As a result we have systems that bring information in at the bottom and process through a series of hierarchical levels to provide a COP that is broadcast across the C4I network. Networks are used primarily to pass highly structured messages.

A hierarchical, message passing, fusion process has worked well to provide a common operational picture but is not suitable for the other phases of command and control. Functions such as operations planning, course of action analysis and plan execution analysis would be better served by different processes that include scenario based simulations, peer-to-peer communications and distributed applications.

2. The Case for Simulations in C4I

Maps have been used for thousands of years as an effective way to conduct warfare. Operational scenarios displayed on maps have proven to be an effective method to perform situation assessments.

This is an effective approach as well for planning operations and controlling their execution. However maps and scenarios must be able to project situations and present various candidate courses of action. Things we cannot readily perform in current C4I systems.

The COP is derived from sensor data and observations to represent the real world situation. A planned situation is by definition simulated. Current C4I systems have neither the means to generate simulated situations or the methods to display them. Nor are they able to apply the real world analysis functions to simulated situations.

Until we have an ability to simulate plans and courses of action, C4I systems will fall very short of their potential support in the "decide" (planning) and "act" (control operations) phases of the command and control cycle. In order for C4I is to adequately support the entire cycle of command and control it must embrace modeling and simulation.

3. The Global Information Grid Challenge

The C4I community is about to embark on unfamiliar courses in the network based Global Information Grid (GIG) and the accompanying GIG Enterprises Services (GES) being publicized by the Defense Department. [2], [3]

The GIG and GES will require new ways to view and use C4I systems as well as new modes of operation. Network based C4I applications will allow people and processes distributed spatially across networks to work on common problems. Peer-to-peer connectivity with much improved information sharing will be possible. The evolution should be addressed and planned.

Rhetorical questions that are, or should be, addressed as we embrace this new technology include: How will modeling and simulations (M&S) play in the GIG? What are the concepts and requirements for network based C4I applications? What M&S GIG Enterprise Services are needed to support those types of applications? What is an appropriate architecture? How should C4I evolve?

4. Network Centric Applications

Network centric applications will bring new requirements to C4I. A major addition to hierarchical processing and the COP broadcast mode that we currently have will be peer-to-peer connectivity with network distributed client/servers and horizontal sharing of information where data is exchanged at the process level rather than the message level.

For example, imagine a cooperative planning session or a course of action analysis that occurs on multiple ships. The individual participants must be able to exchange knowledge and intent about the plan as it evolves. A change in the scenario initiated on one person's screen gets reflected on the others' screens. This requires the synchronization of the planning processes rather than merely passing messages.

Distributed applications will come into play that allows collaborative planning, coordination and decision support. This new capability will require the sharing of unprocessed and uncorrelated data with selected users on demand.

5. The Embedded Simulation Infrastructure (ESI) Program

Limitations in C4I have been cited. Does this mean that the basic C4I architecture is flawed or cannot be adapted to support the "decide' and "act" phases of command and control? Absolutely not! The shortcomings are in the lack of suitable processes that support simulation based applications. Network Centric Applications will require several new key C4I technologies currently not contained within operational C4I systems.

The Navy Modeling and Simulation Management Office (NAVMSMO) has taken a two phase approach to moving C4I into the department of Defense Common Operating Environment (COE) [4] and into the Global Information Grid (GIG).

- **Phase 1** – Develop embedded simulation technologies to get simulations to work at all in operational C4I.
- **Phase 2** – Expand the technologies for Network Distributed Applications

The goal of NAVMSMO's C4I Embedded Simulation Infrastructure (ESI) Program during Phase 1 was to define a suitable architecture concept for simulation based C4I applications and to develop sharable modeling and simulation (M&S) software components to be used in their construction. Significant progress has been made and will be discussed.

Basic M&S Requirements

- Simulated Data Management
- Variable Time Base Management
- Scenario Generation
- Embedded Client/Server Architecture
- Sharable M&S Software Components
- M&S Host Application Architecture

Network Enabling Requirements

- Distributed Applications
- Peer-to-peer Connectivity
- Application Tailored Data Exchange
- Scenario Runtime Synchronization
- Application Database Synchronization
- Distributed Scenario Development
- Dynamic Runtime Services

Figure 1
Simulation Technologies Required for COE/GES

The requirements listed in Figure 1 were identified as basic needs for embedding simulations within COE compliant C4I systems and for the development of distributed applications such as planning and COA analysis.

Core services were required to link simulations to the C4I functions, manage simulated data and variable time bases. Architecture concepts were needed to provide standards for integrating simulations into C4I and providing standards for the development of sharable M&S software component.

6. Sharable M&S Software Components

The ESI Program undertook the development of a set of sharable software components that would satisfy the basic M&S requirements identified in Figure 1. A number of sharable M&S software components, models and tools have been developed and are listed in Figure 2.

This table is broken into three types of software components. The Core M&S Services are sharable software components that are integrated into simulation based applications. They consist of functions that are very common to simulation based applications. These services support a class of scenario based applications such as planning, training and course of action (COA) analysis.

Plug-in Models are mini-simulations that are compatible with the M&S services and are easily included in an application. Plug-ins have a specific software interface and generally have their own tab in the application graphical user interface (e.g., would appear next to the Scenario, Track , Dynamic Run and CMT tab in Figure 3). A small number of Plug-ins have been developed.

The Development Tools listed are components that are useful in the development process. The C4I Simulation / Stimulation tool allows a developer to simulate a GCCS/M system that can generate a simulated COP and stimulate a C4I system through a communication channel.

Core M&S Services
- Common Operational Picture (COP) Capture
- Mission Editor
- Time Line Display / Editor
- Virtual Track Manager
- Plan Preview
- Dynamic Run (Time base Management)
- Exercise Track Management System (XTMS)
- Archive
- Replay
- Debrief Editor
- Event Manager
- HLA/RTI Ambassador
- ATO Parser
- DIS Server
- Training TUTOR

Plug-in Models
- Visibility Manager
- Mobile Sensor Model
- Visual LOS Model
- Data Base Interface Plug-in
- UAV Model

Development Tools
- C4I Simulator/Stimulator
- Training AUTHOR
- Host Applications

Figure 2
Sharable M&S Services, Models & Tools

This is very useful for testing applications and designs. The Training Author is a tool for creating training scenarios and lessons. This tool works in conjunction with the C4I Team Training System (CTTS) and the Training Tutor, which is one of the M&S Services that an application can include to run embedded training.

7. M&S Services Descriptions

Several of the M&S Services listed in Figure 2 will be discussed briefly.

COP Capture is a function used to extract the real-time C4I common operational picture and provide it to an application as a starting point for a scenario to be built, or to initiate a course of action or plan. Several filters are available to limit track types, time period and geographical areas.

The *Mission Editor* component, shown in Figure 3, is a robust scenario generation and editing capability. It is used in training; planning and COA analysis applications for force lay down of entities and routes and to simulate movement along those routes.

The Mission Editoris used to create and edit the time based scenarios and store them in the Virtual Track manager (VTM). Scenarios are saved in Extensible Markup Language (XML) or Over-The-Horizon Targeting Gold (OTG) formatted files.

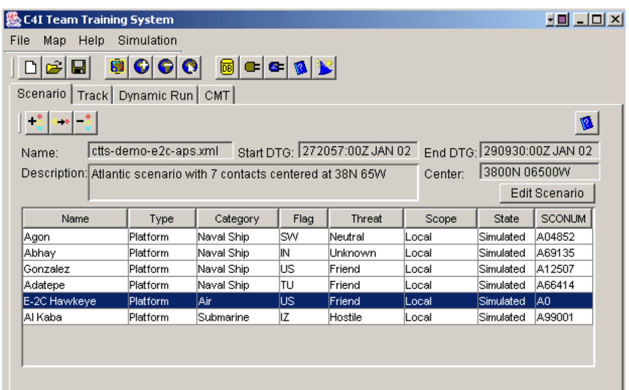

Figure 3
CTTS Mission Editor

The Mission Editor has an intuitive user interface and contains features that allow a user to rapidly create and modify scenario track and waypoint objects. The Mission Editor acts as a core functionality of many applications around which other features and plug-ins are built.

The *Virtual Track Manager (VTM)* component is the low-level software for storing and manipulating scenarios made up of simulated forces. The VTM stores the time based scenarios in memory as tracks, waypoints, and events. The VTM contains functions (Java methods) for creating and manipulating the tracks. Unlike the other services, the VTM has no graphical user interface but interacts with other M&S components such as the Mission Editor, COP Capture, Scenario Preview and Dynamic Run. An application accesses the VTM through application programmer interfaces (APIs), which are public Java classes and methods.

The *Scenario Preview* capability (also called the Plan Preview in some applications) is used to run and preview a scenario stored in the VTM during its development. It is used in conjunction with the Mission Editor and can display all the waypoints of a track as a Path of Intended Movement (PIM). The scenario may be automatically time stepped or viewed in time slices by adjusting a time slider bar. The scenario is displayed on the GCCS-M default system map but not inserted into the TMS, therefore the GCCS-M system functions cannot operate on the scenario during preview.

The *Dynamic Run* function processes the VTM scenario during an application runtime. Several options are available that effect how the dynamic scenario is provided. The output can be inserted into the GCCS-M TMS or provided to the simulation to process, depending on the application requirements. For example the stored scenario could be the “ground truth” input which gets converted to a “perceived picture” by a training simulation, which is the case for the embedded Simulation Server plug-in in the C4I Team Trainer (CTTS) described later.

The *Dynamic Run* component extracts a planning or mission scenario from the VTM and produces the dynamic ground truth picture as the input to a planning or analysis simulation. Scenario tracks are then analyzed according to the needs of the application. They can be modified to simulate sensor inaccuracies and deviations in a training application or analyzed by a simulation to determine vulnerabilities in a postulated course of action.

The scenario reports may be provided to an embedded simulation for analysis or inserted directly into the GCCS-M Track Management System (TMS) for distributed as simulated (e.g., planning) tracks across the GCCS-M LAN and reported to the *Simulation COP*. The Simulation COP (SIM COP) provides an application the means to display simulated data in the common operational picture map display so that it protects the real world C4I data but allows all COE and GCCS-M software segments to operate on the simulated data in the same manner as real.

The *Archiver* component has been integrated into advanced C4I embedded training applications. [1] The Archiver can archive real world tracks from real time operations and training exercises, as well as scenarios generated by simulations or the Mission Editor of CTTS. The archive files are saved on the system disk in either XML, OTHG or in the internal C4I data object format.

The *Replay* component will allow the playback of archived C4I track data, either from real world operations, training exercises, or from training scenarios and simulated outputs. It replays the tracks within the GCCS-M system as simulated data. All C4I applications are active during replay and operate on the data the same as on real world C4I data.

Other M&S services currently being developed include a *Debrief Editor*, a *Timeline Display and Editor*, an *Event Manager* and an *Exercise Track Management System* (XTMS).

Examples of a Plug-in Model (Visual LOS) and two Development Tools (C4I SIM/STIM and the Author) will be described.

8. Models and Development Tools

The *Visual Line-of-Sight Model* is an example of a Plug-in Model that a developer can incorporate in the design of a simulation based application. The LOS model operates on standard digital terrain elevation data (DTED) to determine where terrain masking occurs in the visual line of sight and those areas where visibility is unobstructed.

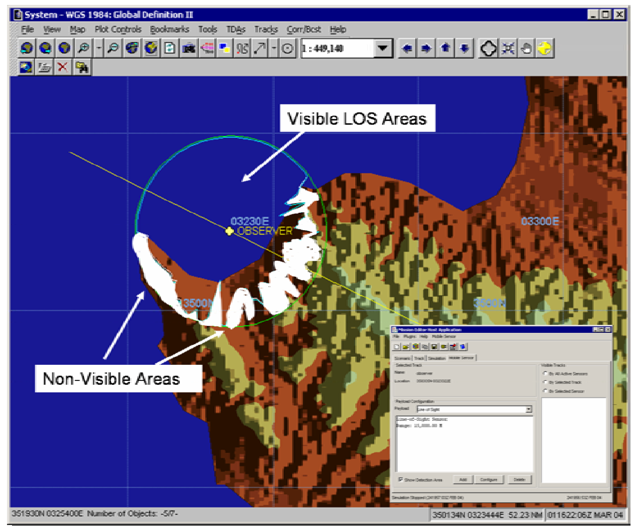

Figure 4
Visual Line-of-Sight Model

The Visual LOS Model is fully integrated with the scenario generation and scenario processing functions and capable of determining if a specific track is visible to an observer or sensor.

The Visual LOS Model can be incorporated into a variety of applications such as UAV route planning, reconnaissance planning or sensor performance predictions.

The *Author* M&S component provides authoring tools that allow the user to define an animated playback, import slides, screen captures, photos or other graphical images, etc., for training or briefing purposes; add pause and stop points; adjust playback speed, and; control the COP display (e.g., center the map or zoom, activate a tactical overlay, etc). The Author is generic in its component implementation. It can be used for a Training Author to create content for operator level training, or it can be used as a Debrief Author for a wide range of briefing and presentation content.

The *C4I Simulator /Stimulator* is a stand alone version of the CTTS that simulates a separate COE system and passes training scenarios through the C4I communications channel rather than inserting directly into the C4I data base. The C4I SIM/STIM is capable of generating training scenarios or of archiving real world operations and playing them back.

9. Examples of C4I Applications

Figure 5 is a list of the C4I applications that have been developed using the technologies described in this paper. A few examples of those applications will be described.

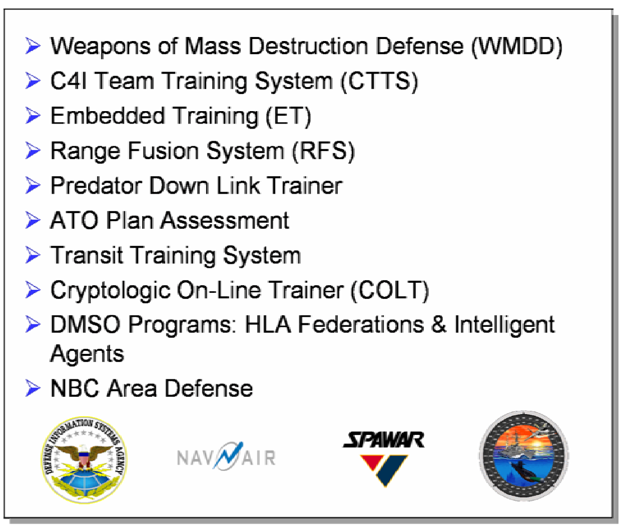

Figure 5
Application Examples

The *Weapons of Mass Destruction Defense* (WMDD) [5] prototype contains the Hazard Prediction Assessment Capability (HPAC) simulation integrated into a GCCS application that is capable of predicting down wind contamination and lethality occurring from a chemical or biological release and integrating this information into the COP. This prototype has transitioned to the Joint Effectiveness Model (JEM) program being executed by Northrop Grumman Information Technology (NGIT).

The *C4I Team Training System* (CTTS) has transitioned to the GCCS/M and is undergoing final integration for release. The *Embedded Training* (ET) application consists of the Training Author and the Training Tutor. These are operator training applications and are also being released in the GCCS/M.

The *Range Fusion System* (RFS) integrates data from multiple range systems into a common ground truth picture during military exercises and provides the fused product to other systems such as C4I, training systems, remote display systems and reconstruction-debrief systems. The Range Fusion System will be a crucial component in the future for mixing real with synthetic forces by providing ground truth for the real world forces. It has been delivered to the Naval Air System Command and an initial system has been installed at the Fleet Air Control and Surveillance Facility (FACSFAC) Large Area Tracking Range (LATR).

The *Predator Down Link Trainer* application uses the common Scenario Generation services as the input into an embedded UAV Visualization Tool (UVT). The output stimulates the Predator down link with a simulated video stream to provide training synchronized with the training scenario being displayed on the C4I system. This application has been delivered to SPAWAR for integration into GCCS/M.

The *Transit Training* application will be used to archive C4I data during Battle Group exercises for play back and training during transits to deployed operational areas. The advantage of this approach is that the trainees are familiar with the exercise since they had just been through it. Scenario editing tools can be used to modify the scenario to add interest and examine alternate threat conditions and courses of action.

The Air Tasking Order (ATO) Plan Assessment, Cryptologic On-Line Trainer, HLA Federation developments and NBC Area Defense are other programs that are currently under development.

10. Embedded Simulation Architecture

One challenge in developing a comprehensive set of embedded C4I modeling and simulation tools is integrating the various components together in a cohesive and logical manner. This section describes the architecture, shown in Figure 6, of the C4I embedded training tools and the design decisions made to integrate this component based software with the COE and GCCS-M. Other applications have a similar architecture.

By using software reusability principals, flexible design principles, and Java software development best practices, the evolving C4I embedded simulation applications will be extensible, allowing for future functions and plug-ins to be added more seamlessly.

A diagram that illustrates the relationship between the C4I Embedded Training components and the COE services (See DII COE Integration & Runtime Specifications Version 4.1 [4]) and application programmer interfaces (APIs) is shown in Figure 6. Previous papers have described this architecture. [6], [7], [8], [9]

The figure illustrates the relationship between the embedded training architecture shown at the top and the COE shown at the bottom. One common aspect of the design is that the training applications are layered over and use the COE through standard Application Program Interfaces (API). No unique interfaces were required. The APIs for the new COE 4.x being released are written in JAVA.

The significant difference between simulation based applications and many other applications are the widespread use of sharable modeling and simulation (M&S) software components that are integrated into the application design. These components described in previous sections were developed in the Navy's C4I Embedded Simulation Infrastructure (ESI) Program as

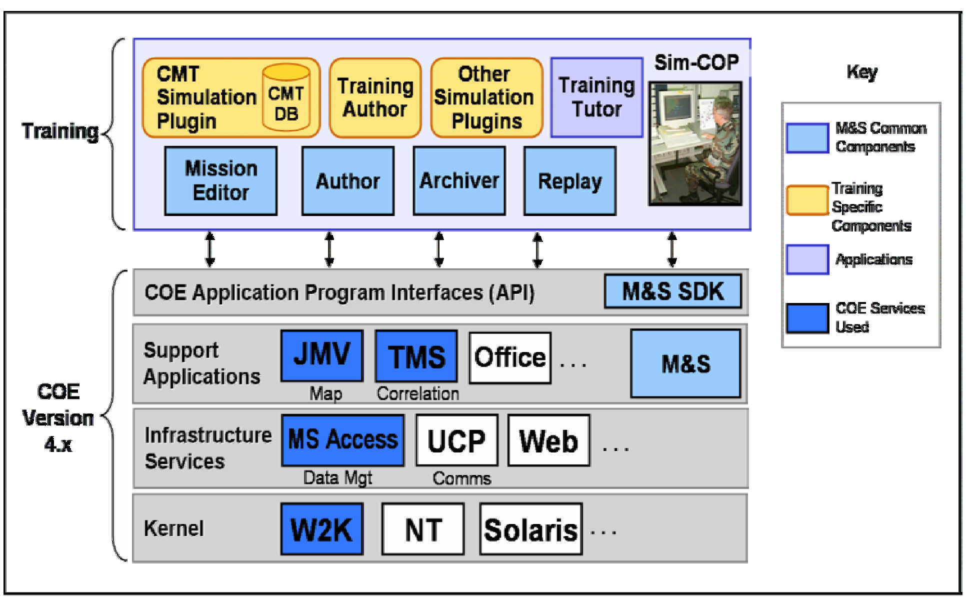

Figure 6
COE/Embedded Training Architecture

extensions to the COE and will soon be available in the Modeling and Simulation Software Development Kit (MSSDK) distributed by the Naval Research Laboratory.

11. Training Host Application Example

The C4I Team Training System example, shown in Figure 7, is based upon the concept of a *training host application* [10], [6]. A host application is a GCCS-M mission application shell tailored to a specific domain, such as training, and serves as a host to multiple embedded simulations applicable to that application.

The Training Host Application contains a set of "core" components and functions that would be necessary for any basic C4I training capability (Shown in blue).

Specific models and simulation components (shown in yellow), known as plug-ins, can be added to build a comprehensive training application for the specific training desired, in this case, CTTS. Other examples of the use of C4I host applications are the Weapons of Mass Destruction Defense (WMDD) Application [8] and the Range Fusion System, mentioned in Section 5.

The training host components of CTTS are derived from the Modeling and Simulation (M&S) Software Development Kit (SDK). The *Mission Editor* component of CTTS is comprised of the M&S sharable software components related to scenario generation and management.

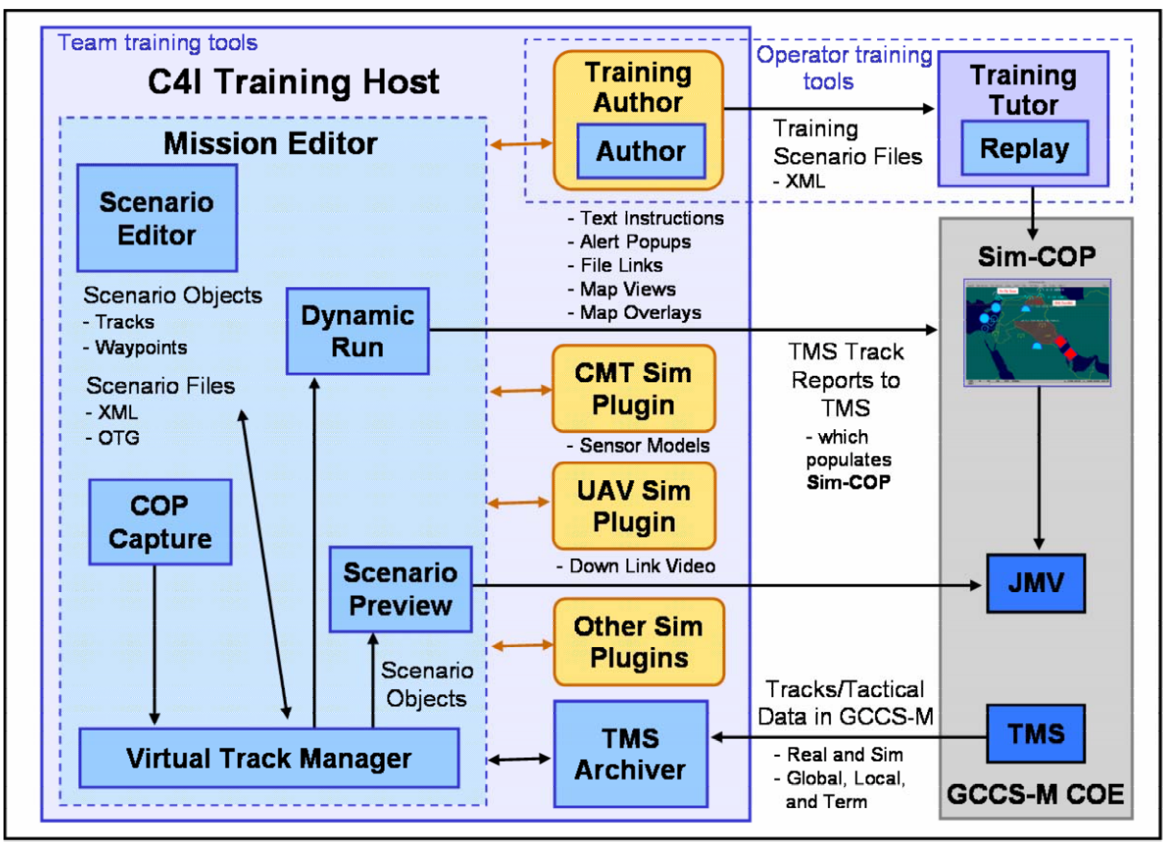

Figure 7
Training Host Application Architecture

These components are the Mission Editor, the COP Capture function, the Virtual Track Manager (VTM), Scenario Preview, and Dynamic Run. The Archive, Replay, and Author components have recently been added to the M&S SDK, and will be incorporated into the CTTS this year.

Additional domain specific components, such as simulations and other applicable plug-ins, can then be added to tailor its use for more advanced team level, network centric, and distributed training applications.

The first release of the CTTS contains an embedded plug-in, the *Cruise Missile Trainer (CMT)* Simulation Server plug-in, which is pre-loaded at runtime. The CMT Simulation Server was adapted from the Cruise Missile Trainer – Personal Computer (CMTpc) training system, whereby the basic functionality of the simulation engine of the CMTpc and Contacts Database are preserved in the CMT Server for CTTS. There is also a feature of the Dynamic Run component that is specific for the CMT plug-in, and it handles the interface between the VTM scenario in memory and the CMT sensor detection analysis and track reporting functions.

12. Current Research: Distributed Applications

The ESI program is currently focusing on extending the embedded simulation technology to encompass distributed applications. An example would be a distributed Operations Planning capability where military personnel at different locations, including ships and land facilities, could collaborate on the development of scenario based plans.

There are three major new capabilities that are being developed. They are the *VTM Server*, *Distributed VTM Data Synchronization,* and *Run Time Synchronization* of simulated data.

Currently the VTM software is embedded within individual applications. A *VTM Server* will allow applications on a local area network to interact with a single copy of the training or planning scenario during its development. Changes made by one of the people collaborating on a distributed application will be reflected on others workstation. The effort is to provide methods to attach separate applications to a VTM Server located on the LAN.

The VTM Server will solve problems for applications that are distributed across a LAN. But because of limited communications bandwidth between two ships and with the shore facilities, a VTM Server is not the solution for applications distributed over a C4I Wide Area Network (WAN).

The *Distributed VTM Data Synchronization* technology will provide a means to synchronize two or more VTMs located on separate LANs. Consider this: An initial planning scenario is developed at one location. A file is sent to initialize a VTM at another location. Both locations can run and analyze the same scenario as long as no changes are made.

The VTM Synchronization function will pass any changes made by one to all others. Since the VTM is primarily a data repository that stores track and event objects it is only necessary to update the data. There are no time synchronization problems other than when two people attempt to change the same track objects. Those conflicts can be resolved. A technique is being developed that uses standard C4I messages to synchronize VTMs. By devising methods that use standard system functions, no COE changes will be required.

The third technology being addressed is *Run Time Synchronization*. This capability is a requirement for distributed applications that require both time and data synchronization such as training or a dynamic debrief that runs concurrently on multiple ships. The approach to run time synchronization that is being examined makes use of dedicated Track Management Systems, designated eXercise TMS (XTMS).

An XTMS is set up on each participating LAN (e.g., ship). Simulated track and event data is passed among XTMSs. The application will determine how the data is processed. There has been some experience with this type of approach. The Range Fusion System mentioned previously makes use of an XTMS to receive the Range data for processing in GCCS/M on board ship. No software changes were required in GCCS/M to accommodate this new type of data.

13. Summary

C4I architecture and process issues have been analyzed to determine proper techniques to integrate simulations into COE compliant C4I systems. A number of sharable modeling and simulation components have been developed and used in more than a half dozen applications. The difficulty of integrating simulations into C4I has been made significantly simpler through the use of bold new embedded simulation architecture and sharable software components.

14. M&S SDK Status

The first limited release of the Modeling and Simulation Software Development Kit (M&S SDK) occurred in 2003. The full unrestricted release of the M&S SDK is planned for this year. It will contain the M&S Services, Plug-in Models and Development Tools described in this paper and listed in Figure 2.

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