

Train as you Fight – Design and Integration Issues for Embedded Training in the Future Combat System

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Abstract

For the past six years embedded simulation research has focused on methods to transform digital-based current force systems, such as the latest version of Abrams tank and Bradley Fighting Vehicle, into systems capable of supporting embedded individual, crew and unit training. This research was spearheaded by the Inter-Vehicle Embedded Simulation Technology (INVEST) Science and Technology Objective (STO). While many technologies still required improvement to meet onboard training needs and size limitations, the INVEST program had great success in demonstrating the potential of the technology for both current and future programs. Based in part on the success of the INVEST program, the Army decided in 2003 to make fully embedded simulation a requirement for Future Combat System (FCS). This paper discusses research focused on embedded simulation capabilities for the FCS.

The Embedded Combined Arms Team Training and Mission Rehearsal (ECATT/MR) STO was initiated in FY03 to explore risk areas for FCS embedded simulation. As a new system start, FCS has the advantage of building embedded technology into the fundamental architecture of the system rather than having to add it later to a fielded system. However, development is complicated by the fact that neither the FCS vehicles nor FCS doctrine are yet defined. This paper discusses the development and application of an embedded testbed as an aid to FCS embedded training concept exploration. The paper discusses testbed use to define a fundamental embedded interface that will permit embedded components to interoperate via a network for large exercises and mission rehearsal. Other technologies being explored for FCS are also discussed such as the vehicle-soldier linkage for dismounted infantry training, intelligent tutoring and the use of C4ISR to control computer generated forces. The paper concludes with a discussion of future work.

About the Authors

Henry Marshall is a Principal Investigator on Mounted Embedded Simulation Technology at the Research, Development & Engineering Command (RDECOM) Simulation Technology Center (STC). Prior to this assignment he worked at the Simulation, Training and Instrumentation Command (STRICOM) where he spent 11 years as lead for the CGF/SAF, HLA and Linux Porting developments on the Close Combat Tactical Trainer (CCTT) system in addition to being a OneSAF team member. His twenty years with the Government have been mainly in CGF and Software acquisition. He received a BSE in Electrical Engineering and an MS in Systems Simulation from the University of Central Florida.

Gary Green is a research associate at the Institute for Simulation and Training, University of Central Florida. He has over 20 years documented success in management and research of training and simulation programs. His recent experience includes six years managing research projects exploring embedded simulation and embedded training issues in support of Army research and development. He is currently the principal investigator for the Institute on the Embedded Combined Arms Team Training and Mission Rehearsal Science and Technology Objective contract with US Army Research, Development and Engineering Command's Simulation Technology Center. He received his MS in Operations Research/System Analysis from the US Naval Postgraduate School.

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Introduction

The US Army is aggressively developing an objective force composed of brigade-sized Units of Action (UA) equipped with the highly lethal Future Combat Systems (FCS). The capabilities of this force are revolutionizing all aspects of the Army, from doctrine to training. Attributes of the FCS emphasize aggressive agility, enemy destruction at extended range, use of unmanned platforms, and commanders empowered to see first, understand first, act first and finish decisively. To train the soldiers and leaders necessary to effectively fight these Units of Action and their FCS platforms, the Army has chosen as the preferred option for all training domains a relatively new technology – fully embedded training.

Background

Embedded training as a strategy that enhances or maintains skill proficiency by allowing soldiers to train using their operational systems. Three methods for building embedded training technology into systems are: fully embedded where training is built into operational systems; appended or strap-on, where equipment is added onto operational systems as a permanent feature, and umbilical or networked, where equipment is connected to operational systems for training. FCS is pursuing fully embedded training.

The Inter-Vehicle Embedded Simulation Technology (INVEST) Science and Technology Objective (STO) was the first significant program to research technologies to support embedded training. From 1997 through 2001 the INVEST program researched technologies and concepts that supported training onboard combat vehicles. This research raised awareness of the potential of fully embedded training, fostered confidence in this emerging technology and produced prototype embedded training systems for the M1A2 Abrams Systems Enhancement Package (SEP)

tank and M2A3 Bradley Fighting Vehicle. Program Managers for these two current force vehicles continue to pursue vehicle modifications that will add embedded training capability to their vehicles. INVEST was a significant factor leading to creation of a key performance parameter (KPP) for embedded training on FCS

The Future Combat System

The FCS is being designed as a family of systems. It is a networked, multi-functional, multi-mission re-configurable system of systems designed to maximize joint interoperability, strategic transportability and commonality of mission roles, including organic and joint, direct and indirect fires, air defense, reconnaissance, troop transport, counter mobility, non-lethal fires, and C2 on the move. Important components of the training architecture include an integrated live, virtual, and constructive (LVC) simulation environment and the standards, protocols, and systems required to stimulate training. In addition, the FCS must be interoperable in the LVC environment with the systems of the Stryker and current forces. The FCS LVC environment will support individual and collective training, and mission rehearsals in the four training domains (home station, institution, combat training centers, and deployed). [UAMBL 2002]

The FCS will be fielded in Units of Action (UA), brigade-sized organizations built around three combined arms battalions as shown in Figure 1. Unmanned platforms include robotic vehicles for assault, reconnaissance and logistics. Manned vehicles such as command and control, direct and indirect fire, infantry carriers and medical support will be designed to maximize the common look and feel between mission planning, training and operations for soldiers to maintain operator, crew, team, and leader proficiency. [UAMBL 2002] Unlike most development programs, contractors developing FCS mission platforms will also develop the training components for those platforms, including embedded training. First

Unit of Action Design

As of Nov 02

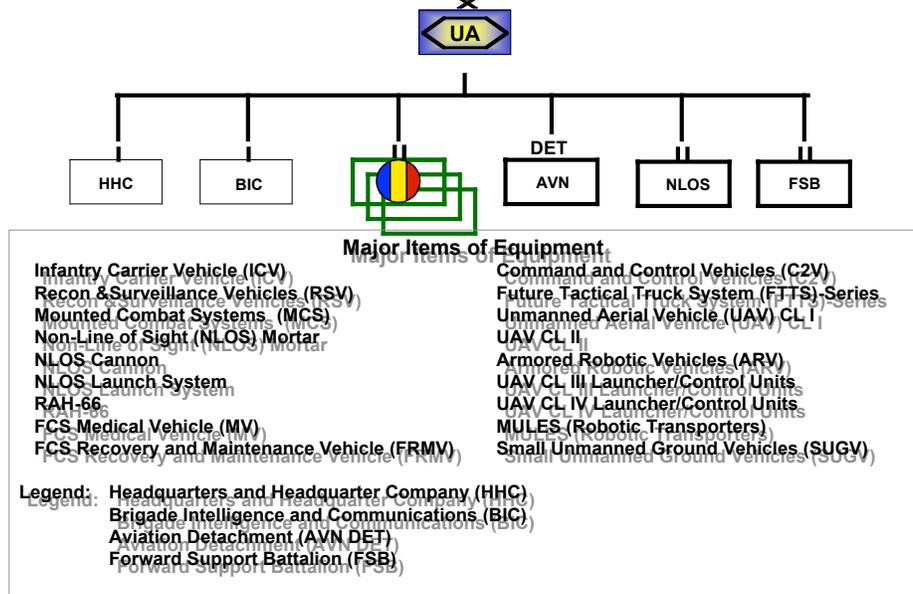


Figure 1: Unit of Action Organization and Major Items of Equipment as of November 2002 [2]

unit equipped (FUE) for Increment 1 is scheduled for FY08, with initial operational capability (IOC) in FY10. Increment 2 fields a more capable UA that possesses a higher density of unmanned systems and has FUE of FY12 and IOC FY14. [TRADOC 2002]

ECATT/MR STO

Overview

For the past several years both the Vetronics Technology Center, US Army Tank-Automotive Research, Development and Engineering Center (TARDEC) and the Simulation Technology Center (STC), US Army Research Development and Engineering Command (RDECOM) (formerly the science and technology element of the US Army Simulation, Training and Instrumentation Command (STRICOM)), have worked to create simulation technologies that could be embedded into close combat vehicles. TARDEC's interests have been primarily in vehicle workload issues, while STC focused on using embedded simulation for training and mission rehearsal. The two organizations have shared research ideas and products through several years of development. With the advent of the Future Combat System, both programs began to focus their research toward this developing system of systems. As the direction of the research became more aligned, other opportunities to share technology were recognized and pursued.

The STC science and technology program focused on embedded training for FCS is called the Embedded Combined Arms Team Training and Mission Rehearsal (ECATT/MR) STO. This STO is developing and demonstrating an embedded, combined arms team trainer and mission rehearsal function for FCS supporting soldiers, crews, and small units. Products of the STO include technologies that will form a framework for future training applications for the range of FCS operations, such as, robotic control and other sensor operations, mission planning/rehearsal, command and control, and maneuver; C4ISR network analysis to support distributed simulations; and vehicle system interface requirements.

The STO will integrate constructive and virtual simulations with live vehicle interfaces creating an "on-board" environment that will allow crews to stimulate vehicle sensors, displays, controls and systems while interacting with virtual terrain and computer generated forces.

The Embedded Training/Mission Rehearsal (ET/MR) Testbed

As one of the Integrated Product Team members of the STO, the Institute for Simulation and Training, University of Central Florida built the ET/MR Testbed as a tool to integrate and demonstrate STO products. One of the issues with FCS research is the fact that no actual FCS system exists and the FCS design is not complete. In addition, the

costs associated with modifying a legacy vehicle to do the embedded development are significant. The most reasonable solution to this issue was to develop a testbed with the goal of transitioning the technologies to an FCS prototype system, such as the crew stations built by TARDEC's Crew Integration and Automation Testbed (CAT) Advanced Technology Demonstration (ATD). The CAT ATD is investigating numerous Vehicle Electronics (VERTRONICS) issues including embedded simulation. The ET/MR Testbed was patterned after the CAT crew stations, but would never be used in a combat vehicle as was the CAT Testbed. Thus it has less fidelity and only implemented a small subset of the CAT capabilities. Figure 2 provides a 3-D rendering of one of the crew stations in the ET/MR Testbed.

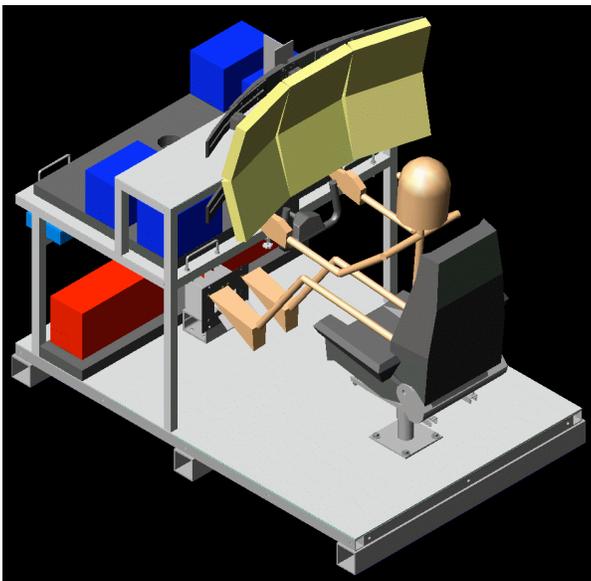


Figure 2: ET/MR Testbed

The ET/MR Testbed will serve as the primary platform for integration of research products from the ECATT/MR and other STC STOs. It consists of two low cost, reconfigurable man-in-the-loop crew stations representing conceptual crew stations in FCS platforms. The operating system is Linux and One Semi-Automated Forces (OneSAF) Testbed (OTB) is used for computer generated forces. The visual system includes nVidia GeForce 4 graphics cards and Carmel Applied Technology's (CATI) XIG image generators. Crew interaction with the simulation is provided by a yoke with eight buttons, touch screens on all six displays, pedals for braking and acceleration and a graphic user interface based on the look and feel of the CAT ATD soldier machine interface. In addition, a wireless keyboard and trackball are available for configuring scenarios. The hardware architecture is shown in Figure 3.

One of the goals for the STO was to build the ET/MR Testbed in a manner that kept the cost low enough so that multiple crew stations could be developed and provided to

other organizations for experimentation as necessary. By reusing simulation software and using commercial products, fully operational crew stations can be reproduced for less than \$20,000 each.

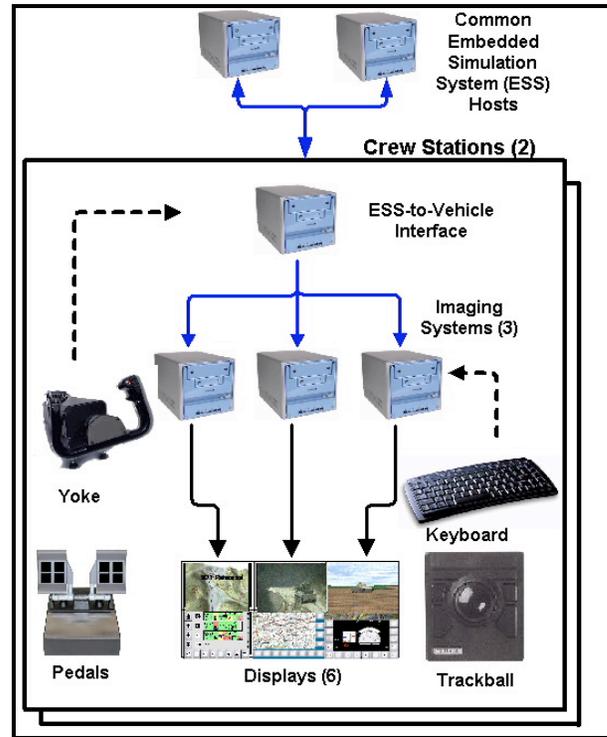


Figure 3: ET/MR Testbed Hardware Architecture

The Testbed software architecture is built around an adaptation of the TARDEC Vetronics Technology Testbed (VTT) simulation system. [Green, Marshall et al 2003] Over a number of years, TARDEC research has evolved a significant body of vehicle simulation software known as an Embedded Simulation System (ESS). Operating on vehicle crew stations, this software simulates sensors, weapons and robotic vehicles and provides an interface for the soldier to interact with these simulated systems. Building on an earlier version of the ESS known as Vetronics Technology Testbed (VTT) the CAT ATD ESS configuration operates on two crew stations that have been installed in a LAV vehicle to produce appropriate crew task loading for mission scenarios to test crew station design and demonstrate unmanned combat. IST adapted the ESS to support the ET/MR Testbed. The basic architecture consists of an A-Kit representing the vehicle and interfaces to the vehicle, and a B-Kit consisting of the ESS. The major components of the ESS are depicted in Figure 4 and briefly described below.

- PIU (Process Interface Unit) – The sole communication channel between simulation components. It allows multiple programs to interact asynchronously in the overall simulation. PIU generally hides details of where other simulation processes execute and inter-process

communication is handled implicitly. All VTT processes use PIU. The PIU is similar to the Persistent Object

Protocol (POP) used by OTB or the SAF Entity Object

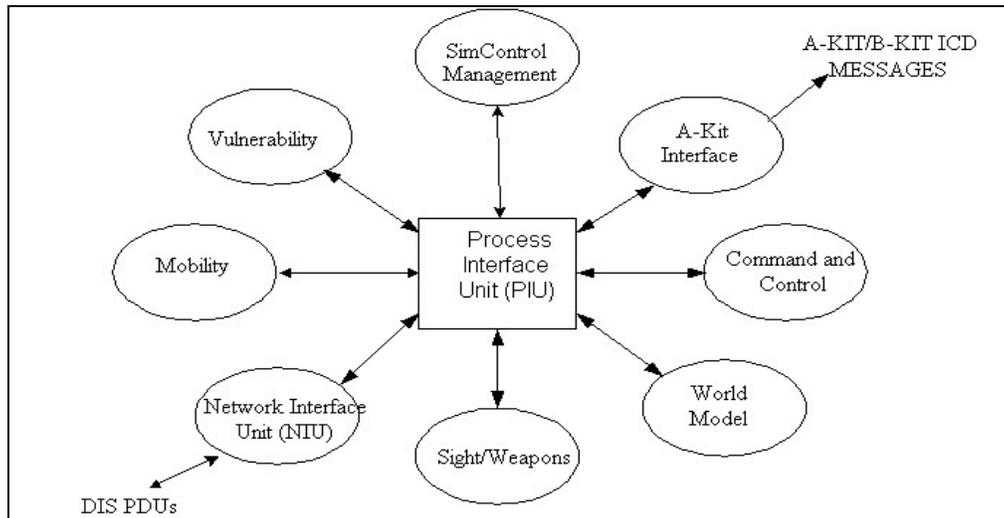


Figure 4 ESS Software Components

Database (SEOD) used by CCTT. Both provide a mechanism to share state information about the systems and processes. Likely the PIU will be replaced by TARDEC in the future, but due to numerous dependencies within the system and the impact change would have, the PIU will continue to be used by the Testbed in order to maintain commonality with the TARDEC architecture.

- World - The link between the image generation visualization software and the PIU/simulation. Traditionally a single host process is used to drive image generator, however the VTT architecture uses many individual components to accomplish the host functionality.
- Sight/Weapons - Line of sight weapons configuration and control. Contains logic for current weapon orientation, weapon type and round flyout.
- AKITInterface - The peer connection to the vehicle or A-Kit. Provides the indirect abstraction for vehicle resident functions and controls. Vehicle-side messages of interest were incorporated into the host program.
- Command and Control (C2) - Monitors and responds to the AKITInterface for incoming Joint Variable Message Format (JVMF) radio message traffic.

- Network Interface Unit (NIU) - The link between the One Semi-Automated Forces Testbed (OTB) and the VTT simulation. It uses Distributed
- Interactive Simulation (DIS) Version 2.04 to relay Protocol Data Units (PDUs) to and from OTB. It uses the OTB libraries for transformations against position, orientation and velocity.
- Mobility - Physics model used to navigate virtual vehicles across terrain databases.
- Vulnerability - Handles incoming round casualty assessment. Uses a geometry model and OpenGVS software for damage assessment.
- SimulationControlManagement - Uses configuration files to locate and start/restart simulation processes. Scripts are executed based on the state of the simulation.

In its current configuration, both Testbed crew stations are configured as robotic control stations in an FCS Command and Control (C2) Vehicle. Each crewstation can also function as driver for the simulated ownship or for remotely controlled robotic vehicles. The six visual displays represent situational awareness, robotic vehicle status display, three out-the-window views representing the view from ownship, robotic sensor(s) or weapons sighting, and vehicle instrumentation (tachometer, heat gauge, etc.). To provide the soldier-machine interface for robotic management, STC has integrated into the Testbed the Operator Control Unit

(OCU) developed by the RDECOM Advanced Robotic Simulation STO and Unit of Action Maneuver Battle Lab (UAMBL) at Ft. Knox. This OCU provides capability for crewmen to plan and execute missions for ground robotic vehicles using the Testbed crewstation touch screens and controls. Another version of the crewstation will be configured to represent crew stations of an FCS Infantry Carrier Vehicle (ICV).

The selection of a terrain database is always an important issue for any simulation or simulator. The database must satisfy the requirements of the planned experiments, providing visual representation and simulation interaction appropriate to the intended purpose. The initial terrain database used in the Testbed is a 3x5 kilometer, high resolution database of a National Guard training area at the Camp Grayling, Michigan developed by TARDEC. Experiments planned for the STO require high resolution databases with both urban and rural maneuver areas. Since the Grayling database has few buildings, plans are to shift later in the program to a database with more urban culture. Several databases are being considered, including a UAMBL version of Azerbaijan and the Fort Polk Military Operations in Urban Terrain (MOUT) site.

The computer generated forces model used in the Testbed is OTB Version 1, modified by UAMBL to include robotic vehicles and other FCS-like capabilities. When OTB Version 2 is released later this year, the Testbed will migrate to this later version.

STO Research Areas

There are four primary technology areas being explored by the ECATT/MR STO. These are integration of mounted and dismounted embedded simulation and training, intelligent tutoring, controlling semi-automated forces (SAF) using command and control (C2) devices, and improved architectures for embedded simulation.

Integrating Mounted and Dismounted Embedded Training

RDECOM STC is researching technology to provide dismounted soldiers with virtual and mixed reality visualization in the Embedded Training for Dismounted Soldier (ETDS) STO. The basic dismounted embedded system is shown in Figure 5.



Figure 5: Prototype Embedded Dismounted System

This system is based on a PC-driven face mounted display that also includes a head tracking device to monitor the trainee's orientation. The dismounted soldier uses buttons on the simulated weapon to move and engage the simulated Opposing Force (OPFOR) seen in the face mounted display. In the near future the PC will be replaced by a small hip mounted unit reducing the systems weight and increasing human factor aspects of the system. The ECATT/MR STO is researching techniques to integrate the dismounted soldier embedded training with embedded training for the FCS Infantry Carrier Vehicle (ICV) in which they ride to battle. The likely FCS embedded use case for an FCS Infantry Platoon mission rehearsal in an assembly area or motor pool is show in Figure 6. This concept will be prototyped by interfacing a dismounted embedded system with the ECATT-MR testbed configured as an ICV. This research will develop prototype interfaces to provide visual situational awareness from the vehicle to its dismounted soldiers. The initial effort will look at methods to continuously show the soldier the direction to his ICV, perhaps by providing a green edge to the soldiers head mounted display on the side nearest the ICV. This work will also explore methods for target handoff between the soldier and ICV. It will also look at techniques to provide awareness to both vehicle commander and dismounted soldier of the soldier's location relative to the ICF for management of ICV protective measures such as reactive armor and active protection systems that have danger zones that must be considered tactically. This area has numerous technology risks that must be addressed if FCS is to have a realistic embedded infantry capability.

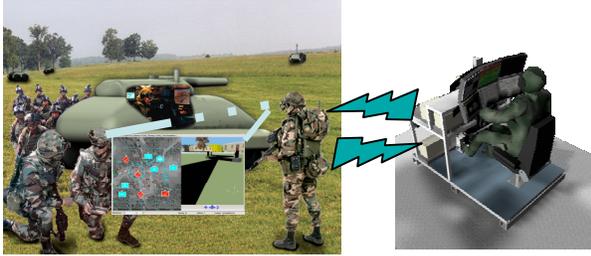


Figure 6: Mounted/Dismounted Embedded Concept.

Intelligent Tutoring

In the future current training facilities will be replaced by units performing embedded training in their vehicles where ever they are deployed. This will make robust training packages more important. One solution to this problem is to make use of Intelligent Tutoring Systems (ITS) for some of the task based training. In many training facilities such as the Close Combat Tactical Trainer (CCTT) much of the task training is at the platoon level with small focused task based exercises, which results in a limited number of outcomes in scenario execution. This reduces the development cost to construct and annotate scenarios to be used by automated after action review mechanisms in an Intelligent Tutoring System (ITS). The STO is prototyping a possible ITS system for FCS embedded training. The prototype intelligent tutor will be based on a use case for robotic management that will reside with a robotic Operator Control Unit (OCU). The STO will explore techniques to coach users through the planning and execution of missions for ground robotic vehicles. The system will provide feed back to the trainee after he/she generates a command to a robot or while the command is being executed. In addition this system will provide an after action review focusing on good and bad decisions the trainee made related to tactics, command formulation, and execution in the software environment. This research will provide insight into what interfaces a system like OTB needs to provide state information to the ITS for performance evaluation. This information could include commands sent, route efficacy, speeds, formations, OPFOR behaviors, etc. One of the critical metrics for this technology is the ease with which additional ITS training scenarios could be created. If successful the prototype will show the utility of making an ITS based system an important part of the FCS embedded training capabilities.

C2 Control of SAF

The design of the FCS calls for both operational and training systems to be the same. Given this, the interface for entering commands to entities in the

Semi-Automated Forces (SAF) during a training exercise is a difficult question, since it is assumed that a dedicated SAF workstation would be undesirable. The logical entry device is one of the C4ISR systems on the vehicle. The STO is exploring the use of C2 systems to manage SAF. This research will attempt to use the Force XXI Battle Command Brigade and Below (FBCB2) system to send control messages to OTB which will translate the commands into behaviors to be used by the OTB controlled entities. If successful, this research will demonstrate capability to manage computer generated forces from inside a combat vehicle using an actual tactical command and control device.

Improved Architectures for Embedded Simulation

Current embedded architectures are based on “standalone” training systems that interface to the operational equipment in a “Black Box” fashion. In the future FCS design it is envisioned that the operational and training systems will be integrated into common components and operate on the same hardware. One possibility for an embedded training architecture is a purely SAF based architecture as opposed to having separate computer components for module (own ship) control and control of Computer Generated Force (CGF) entities similar to current embedded architectures. To explore this concept a SAF based single host architecture prototype, configured as shown Figure 7 is being developed as part of the STO.

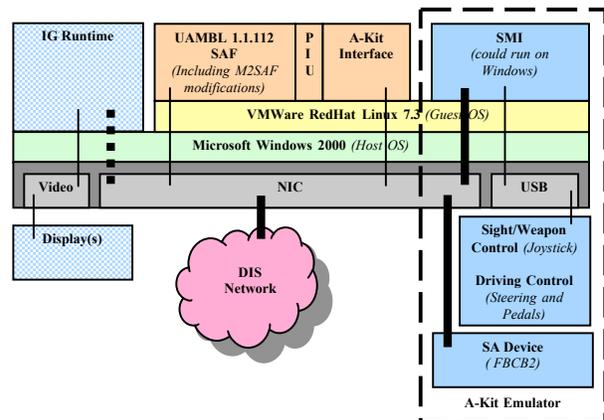


Figure 7: Prototype Single Host Embedded Architecture based around SAF control

In the past, work has been done to over ride behavioral controls of CGF entities with inputs from other devices such as joysticks to provide a low cost interface to in simulated entities. This work is now being extended to explore development of a “composition” of CGF that would support the fidelity demanded by manned simulators as the core of an embedded architecture in a single host environment. Examples of possible areas of

performance concern are CGF vehicle dynamics and the slow rates of turrets since the CGF physical models lack realistic fidelity in these areas and could result in negative training. The development will also include benchmarking to determine where performance roadblocks exist in this architecture. If successful the plan is to integrate this architecture into the ECATT/MR ICV variant for a more demanding test case.

C4I Simulation Bandwidth Requirements

To perform collective embedded training and mission rehearsal, systems must be networked to share simulation and C4ISR information between FCS platforms. Possible solutions to this distributed simulation issue include sending the information over a wireless C4ISR system or routing wires between systems. The wireless solution has security and emission issues that could be a problem depending on the unit's location. The wire solution requires a close proximity between systems which may be a problem in use cases that require the systems be separated. One such FCS use case is illustrated in Figure 8. This use case from the Objective Force FCS Organizational and Operational Plan [Vargas, Demara 2003] is on-route mission rehearsal. In this scenario eight planes are on-route to a world problem area, each carrying three FCS vehicles. The FCS crews are rehearsing a mission while traveling in the planes. The OPFOR is played remotely in the US and is transmitted off a satellite link, the three vehicles in the plane are connected via wire and the inter-plane traffic is handled by a wireless system. Research to estimate the minimal wireless bandwidth required to support a likely simulation was performed by the University of Central Florida during a research program preceding the STO. [4] This research was based on running a discrete system simulation of the computer network. Time stamped data was collected from a representative OTB scenario and entered into the simulation.

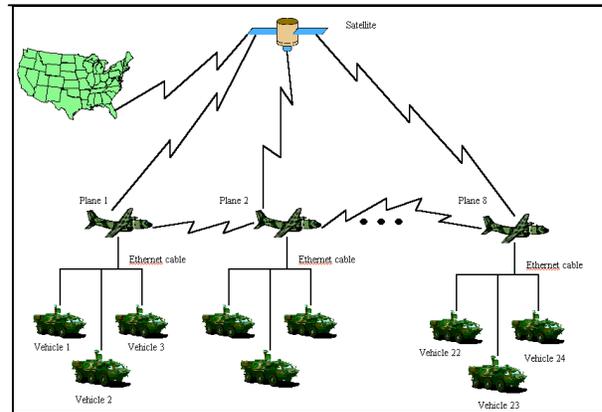


Figure 8: FCS Communication Scenario for doing Mission Rehearsal on Route to the Combat area

One of the major issues observed in the OTB time stamped data was that the scheduler seemed to concentrate events into spikes rather than spread them out over time. To operate well in a wireless mode future event schedulers will have to be optimized to avoid spikes in scheduled event queuing. The results of the simulation showed that wireless networks in the 64KB area would likely be insufficient while those above 200K would be adequate to support this mission rehearsal scenario.

Experiment Plan

To orchestrate the proof of concept experiments and demonstrations of the STO, an experiment plan is being developed. This plan will layout the when, where, what and who for STO experiments and demonstrations. It will also delineate the objectives, scenarios and expected outcomes for each experiment or demonstration. The plan is shown in Figure 9.

A series of stand-alone demonstrations are planned to show progress in areas such as mounted/dismounted situational awareness and intelligent tutoring. Once a satisfactory level of capability has been demonstrated, these technologies will be integrated into the ET/MR Testbed for further testing and demonstrations. Planning is underway to demonstrate STO technologies

at the Inter-Service Industry Simulation and Training Conference (I/ITSEC) and at the Association United States Army (AUSA) winter symposium.

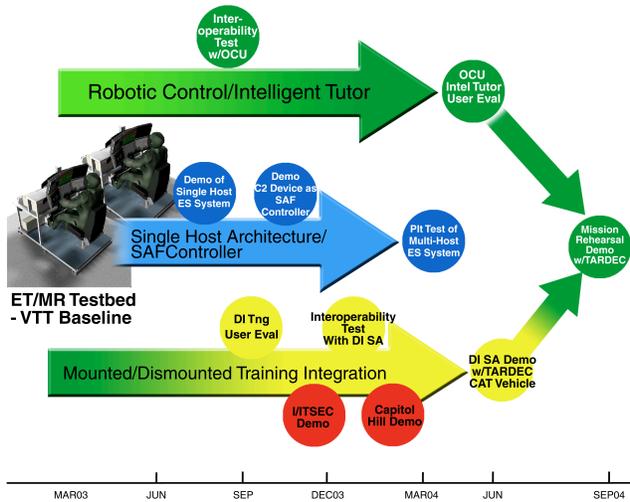


Figure 9: Demonstration and Experiment Plan

The culminating event for the STO is a joint experiment being planned with TARDEC and the CAT ATD FCS-surrogate vehicle. In this experiment, STO technologies will either be integrated into the CAT vehicle or networked via the Testbed for demonstration of intelligent tutoring, robotic management, and mounted/dismounted situational awareness.

Future Plans

To date, embedded training has been limited to individual platforms. The ECATT/MR STO is making the first steps to pursue training for small units. The Objective Force and Future Combat System will require training interactions and communications among large numbers of embedded training systems. Building off the results of the ECATT/MR STO, RDECOM STC is planning an ATD beginning in FY05 to investigate technologies associated with distributed embedded simulation for company, battalion or UA level exercises. The ATD is also considering the inclusion of embedded testing as another user of embedded simulation. Distributed embedded simulation will support the development and evaluation of concepts for dismounted soldiers, manned ground platforms, and unmanned assets to interoperate within a common embedded simulation environment for both training and mission rehearsal.

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