Embedded Distributed Training: Combining Simulations, IETMs, and Operational Code

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ABSTRACT

Sustainment training on the operation and maintenance of high availability systems is difficult since the system cannot be taken out of service for training purposes. However, the operators and maintainers must be well trained to react quickly to events that could jeopardize system availability. Web-delivered simulations are a good way of providing such training because they won't affect system availability and are widely available.

High availability systems require sophisticated system control software to support fault tolerance and online maintenance. These systems and their Interactive Electronic Technical Manuals (IETM) are becoming much more tightly integrated, and use of the system control software is an essential part of operation and maintenance training. The best way to train interactions with this software is to incorporate as much of the actual software as practical into the simulation, so that the operator/maintainer "trains as he fights."

This paper describes a simulation that was developed to train 31S MOS soldiers how to operate and maintain the AN/GSC-52A ground strategic satellite communication station. This simulation required integration with the strategic software for system Control, Monitoring, and Alarms and with the system IETM. This simulation was developed to support conversion of 31S to assignment oriented training. The simulation includes a "system control and indicators" lesson that shares its content with the corresponding section of the IETM. A signal flow lesson is used to help the student visualize the content of the "concept of operations" section of the IETM. Operational lessons include pre-operational checks and restoring communications links. Troubleshooting lessons include the use of test equipment such as spectrum analyzer.

Web-based delivery of these simulations presents challenges for balancing training requirements and delivery systems and capabilities. This paper describes some of the tradeoffs made in the development of this simulation.

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INTRODUCTION

The Signal Center at Ft. Gordon is leading the implementation of lifelong learning for the Army (Wilson and Helms 2003). Three years ago, the Signal Center developed a University of Information Technology master-plan to deal with these issues. Key elements of the UIT concept are:

- **Assignment-Oriented Training**, which means focusing schoolhouse training on the soldiers initial assignment and providing Distributed Learning for soldiers changing assignments to different types of units (e.g. from a tactical comms unit to a strategic comms unit). One of the first four MOS to convert to Assignment-Oriented Training (AOT) is the 31S.
- **Simulations** are a key technology for providing the quality of training that makes AOT possible. The Signal Center is using Virtual Reality simulations that are delivered over the Internet from the UIT website to unit computers for training soldiers going to different assignments (Helms, Frank, Morris 2001). The AN/GSC-52A simulation described in this paper is designed to support 31S AOT.
- **Lifelong Learning Centers,** which support unit training by providing a variety of distant educational experiences. The UIT Lifelong Learning Center (LLC) provides the AN/GSC-52A simulation as a download from its website.

This paper describes a simulation that was developed to train 31S MOS soldiers how to operate and maintain the AN/GSC-52A ground strategic satellite communication station. This simulation required integration with the strategic software for system Control, Monitoring, and Alarms and with the system IETM.

Many of the lessons learned about interfacing AN/GSC-52A operational software with the virtual environment and the simulation will apply to the development of embedded training applications.

31S ASSIGNMENT-ORIENTED TRAINING

The 31S Military Occupational Specialty

The Signal Center teaches communications systems and information technology to Army soldiers. These skills are becoming more critical as Army becomes more digitized and more network-centric.

The 31S is operator and maintainer of tactical and strategic satellite ground terminals, both mobile and fixed terminals. On strategic systems like the AN/GSC-52A, the 31S is responsible for both Operational Maintenance and DS/GS level maintenance. Operational maintenance includes diagnosis and repair by removal and replacement of Line Replaceable Units (LRUs) such as an up-converter, down-converter, or server CPU. DS/GS level maintenance involves opening a defective LRU, and diagnosing components inside the LRU, such as circuit card assemblies, power supplies, etc. DS/GS level maintenance typically involves a more sophisticated set of tests, maintenance, and diagnostic equipment than is required for operational maintenance.

The Need for 31S Assignment Oriented Training

Since civilian use of satellites is expanding rapidly, military satellite communications equipment is evolving at a similar pace, resulting in more equipment to train and frequent upgrades to the equipment that has been fielded. The digitization of the US Army has increased the need for high-bandwidth satellite communications. Soldiers with the skills to operate and maintain this equipment are consequently in high demand in the Army. Soldiers with 31S training are very valuable in the civilian world, so the Signal Center has been tasked to provide a high training throughput. In addition to using the AN/GSC-52A simulation for AOT training by soldiers in the field, the Signal Center is also installing the simulation into personal computers in classrooms at Ft. Gordon in order to support more concurrent training in the schoolhouse.

The Return on Investment of 31S AOT

Before conversion to AOT, the 31S Advanced Individual Training (AIT) course lasted 39 weeks and 1 day and included training on both tactical systems and strategic systems like the AN/GSC-52A. If the STAR-T training had been added to the 31S responsibilities, the AIT course would have increased to 41 weeks. However, 60% of 31S students go to tactical units and will not use their strategic system training unless they are reassigned to a strategic site, which happens very rarely. With assignment-oriented training, the 31S AIT course for students going to tactical units has been reduced by 39%. At the same time, the number of student trained rose from around 100 in 2002 to over 500 in 2003.

THE AN/GSC-52A SATELLITE GROUND STATION

Overview of the AN/GSC-52A

The AN/GSC-52A satellite communications ground station is part of the Defense Satellite Communications System (DSCS). This system works in the X band of Super High Frequencies (SHF). The AN/GSC-52A is a permanent ground station.

The GSC-52A ground station antenna (shown in ***Figure 1***) receives signals in the 7.25 to 7.75 GHz band from the DSCS satellite. These signals are preamplified by a Low Noise Amplifier (LNA), distributed by signal dividers to downconverter racks, and further distributed by signal dividers to the downconverters. The downconverters converts the signals to 70 or 700 MHz frequencies and are sent to the DCSS via patch panel to be demultiplexed and distributed to the source users.

Signals from DCSS at either 70 or 700 MHz frequency are distributed by a patch panel to upconverters that perform amplification and upcoversion to the 7.9 to 8.4 GHz SHF range. Each SHF transmit signal is routed through power combiners, combined with other transmit signals to form a composite RF signal, amplified by a network of redundant High Power Amplifiers (HPAs), and transmitted by a high-gain narrow-beam antenna to the satellite.

Figure 1. Photograph of an AN/GSC-52A Antenna and Elevated Equipment Room

AN/GSC-52A Subsystems

The AN/GSC-52A ground station is a “system of systems,” occupying several racks of equipment in multiple rooms, as shown in ***Figure 1***. The Elevated Equipment Room (EER), which houses the LNAs, the HPAs and their power supplies, is the box just below the antenna. The ECU is the small white shed next to the pedestal base. The pedestal base houses the servo mechanisms for moving the antenna. The main equipment room is in the brick building at the right.

The GSC-52A ground station component systems include:

- **The Control, Monitoring, and Alarm Subsystem,** which controls and monitors the operating parameters of all the major components of the system and generates alarms when parameters move out of acceptable ranges.
- **The Frequency Conversion Group**, which performs upconversion and downconversion to translate between SHF signals used for transmission and receipt of satellite signals and the user signal 70 or 700 MHz signals used by DCSS.
- **The Antenna Subsystem**, which sends and receives X-band signals and provides directional signal strength information that is used to automatically track the satellite. The Antenna Subsystem includes the servo motors that position the antenna and automatically track the satellite.
- **The Transmitter Subsystem**, which uses a network of redundant HPAs and their supporting High Voltage Power Supplies to amplify the composite transmit signal up to 2KW. The Transmitter Subsystem is housed in the EER.

- **The Receive Subsystem**, which takes the low-gain, high-noise RF signal from the satellite through the antenna, and uses a redundant LNA system to amplify the signal so that it can be downconverted.
- **The Frequency and Timing Subsystem**, which uses a redundant combination of cesium standards to generate and distribute the precise timing signal required for SHF communications.
- **The Performance Measurement Subsystem**, which tracks the actual value of system parameters against the parameter values specified in the terminal operating plan. The PMS includes built-in test equipment including spectrum analyzers, power meters, signal generators and a test translator.

Figure 2 shows the simulation's virtual view of main equipment area as seen from the maintenance area. The downconverter racks are on the left, and the upconverter, frequency and timing subsystem, and performance measurement subsystem racks are on the right. In front of the racks is the main console with the terminal monitor and spectrum analyzer.

Figure 2. Screen shot of the AN/GSC-52A Main Equipment Area

Due to the criticality of the communications traffic provided by this system, the system has been designed to provide very high availability through the use of fault tolerance techniques using extensive redundancy. The operator plays a key role in making sure that the system configuration provides these fault tolerance mechanisms the flexibility that they need to assure high availability.

AN/GSC-52A IETM and the CMA

The AN/GSC-52A IETM is implemented as a large number of hyperlinked HTML pages. ***Figure 3*** shows and example of an IETM page. The IETM is cross-referenced by a database that is accessed by the CMA.

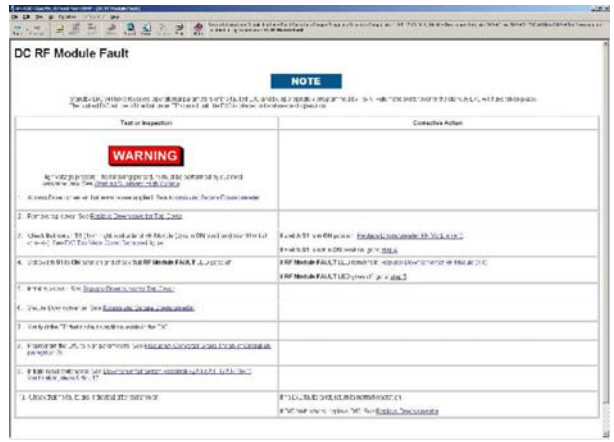

Figure 3. IETM Troubleshooting Description

The CMA is distributed software running on two sets of redundant commercially available computer servers. The CMA software includes:

- **The Terminal Manager**, which provides the primary user interface for the AN/GSC-52A and which maintains the operation plan. The Terminal Manager software and the IETM reside at the main and remote consoles and in a laptop that can be connected to any of seven access points on the CMA Local Area Network (LAN). In normal operation, two Terminal Manager screens are operating and visible, but only one can be used to make changes.
- **Terminal Server A software**, which monitors and controls the frequency conversion subsystem, the frequency and timing subsystem, and the performance management system. Monitoring includes polling the status of devices. Control includes implementing the automatic switchover, which is the heart of the fault tolerance capabilities of the system. Terminal Server A includes a Primary and Secondary Terminal Server set for redundancy.
- **Terminal Server B software**, which monitors and controls the antenna subsystem, the transmitter subsystem, the receiver subsystem, and the environmental control unit. Terminal Server B also includes a Primary and Secondary set of Terminal Servers for redundancy.

In addition to the 3D virtual world, the simulation uses two tabs to provide interactive, high-resolution 2D views of the two consoles running the Terminal Manager software. The student must select the correct tab to get to the console that is in control. Clicking on the main console or the remote console, within the 3D environment, will bring up the appropriate CMA tab.

Figure 4 shows the Earth Terminal CMA display. Each major box represents a subsystem, with separate blocks for the upconverters and downconverters. The status of the different components is shown by color codes, with green for online, blue for standby (a hot spare for the fault tolerance system), yellow for components in maintenance mode, and red for faulty units. Grayed out units have not been installed or communication with the units have been lost in this AN/GSC-52A configuration.

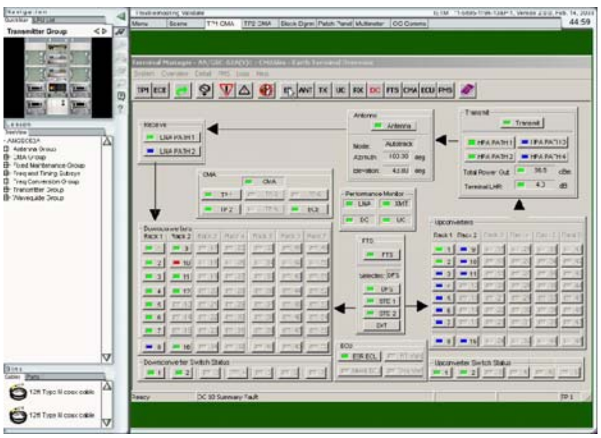

Figure 4. CMA Overview Screen Capture

The CMA is closely linked with the AN/GSC-52A IETM. If the user clicks on an entry in the error log, the CMA launches the IETM page with a listing of possible symptoms for the fault. The user selects the appropriate symptom and the IETM switches to a detailed series of steps to correct the fault. The user can launch the IETM at any time from the CMA help button.

THE AN/GSC-52A TRAINING SIMULATION

Using Simulations for Learning by Doing

The GSC-52A simulation is a collection of simulation scenarios, each with their own initial conditions and appropriate levels of scaffolding to enhance the learning experience.

The levels of student support scaffolding used in the GSC-52A simulation are based on the Familiarize, Acquire, Practice, and Validate (FAPV) method for self-paced learning by doing (Frank 2000). The FAPV method provides multiple scenarios for learning a specific set of tasks and associated Performance Measures. A typical major task will have a single Acquire lesson, and several Practice and Validate scenarios.

In the Acquire mode, the learner is shown the process for the task in a lock-step format. However, the learner is expected to perform the relevant tasks in the simulation environment, so that by the end of the Acquire lesson, the student will know how to operate the simulation as well as having participated in performing the task according to the "school solution."

For the GSC-52A simulation, the Acquire mode lessons were extended with preambles that familiarized the student with the CMA displays and with the TMDE used in the lesson. For Restore and Troubleshooting Acquire mode lessons, the fault was introduced into the equipment in the middle of the preamble. The final section of the preamble shows the student the differences in displays between the unfaulted and faulted system.

For the Practice mode, multiple scenarios are provided so that the learner can accomplish the task under a variety of realistic scenarios. The learner can cycle through all of the scenarios as many times as is needed to understand the task process and variations in the process associated with different scenarios.

For the Validate mode, the learner is required to perform the task under one or more scenarios. The simulation selects the scenarios in order to ensure that the learner can perform the task under a variety of circumstances, as they will have to do in real life.

In a Validate mode lesson all the feedback is saved to the end of the lesson and is documented in an After Action Review (AAR) report that could be sent back to a Learning Management System (LMS) at the Signal Center. Student records data maintained includes which lessons have been completed, the order in which they are completed, and for Practice and Validate lessons, the elapsed time to complete the lesson. The AAR contains GO/NOGO data on each Performance Measure that is associated with a Validate lesson. ***Figure 5*** shows an example AAR report. Consistent with the way that Performance Exams are graded at the Signal Center, the student is graded in terms of GO/NOGO evaluations of the critical tasks and

Performance Measures extracted from the ASAT database for this MOS. The AAR is also provided at the end of each Practice mode lesson to support reflective learning by the student.

The AN/GSC-52A Simulation Scenarios

The GSC-52A simulation includes several types of lessons:

- **Controls and Indicators**. This familiarization lesson uses the virtual environment to help the student understand not only what the controls are but where they are located. This type of lesson is particularly important for physically large systems like the GSC-52A, with multiple rooms and many racks of equipment. The GSC-52A uses a complex component identification numbering and it is important for the operators to know from an error message which component is referenced by the message.
- **Signal Flow**. This familiarization lesson helps the students understand the functions of the different subsystems and also the different fault tolerance mechanisms used in the subsystems.
- **Pre-Operational Checks**. These lessons teach the student to do a visual inspection of the equipment and make adjustments that will reduce the risk of losing a link. These kinds of checks require a basic understanding of how the fault tolerance and satellite auto-tracking mechanisms work.
- **Satellite Acquire and Track**. These lessons teach the student how to acquire a satellite and establish an auto-tracking pattern.

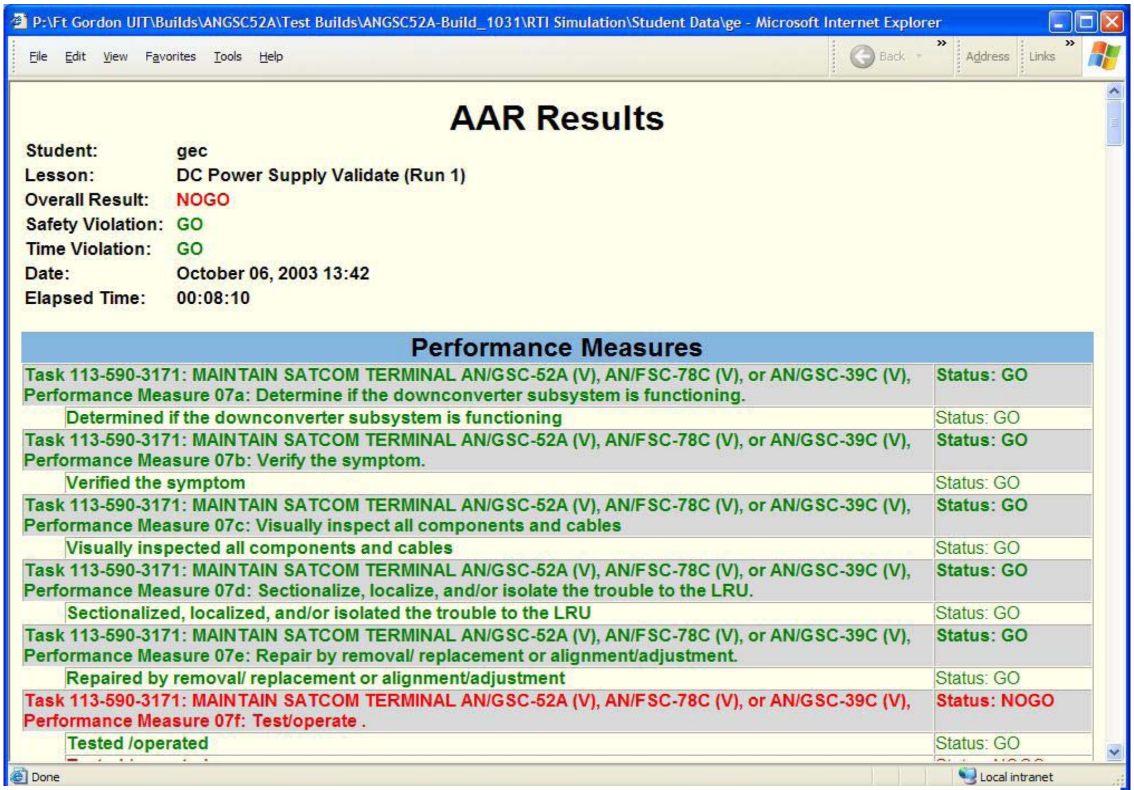

Figure 5. After Action Review Report for an AN/GSC-52A Troubleshooting Lesson on a Downconverter Power Supply

- **Loopback and Power Adjustment**. These lessons teach the student how to use some of the performance monitoring and test equipment, including the Spectrum Analyzer and the Test Translator, in the context of GSC-52A equipment. ***Figure 6*** shows the spectrum analyzer being used to adjust power on an upconverter that has gone out of range.

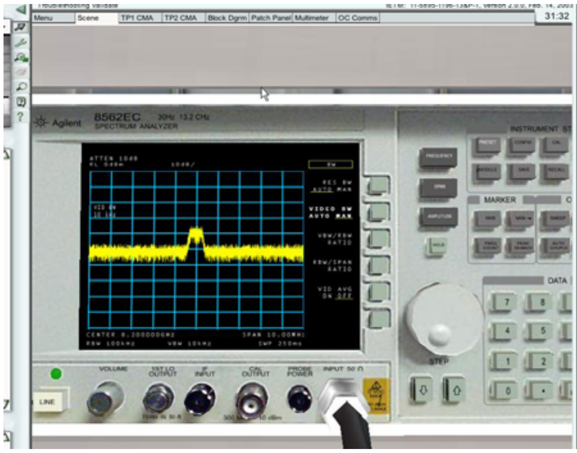

Figure 6. Spectrum Analyzer Being Used to Adjust Power

- **Restore Communications**. These lessons focus on the paramount concern of these strategic satellite systems, which is maintaining continuous service. They are similar to troubleshooting lessons, but do not require that the faulty equipment be replaced or repaired, only that the communications services be restored as quickly as possible. The time limit standards for restore practice mode and validate mode lessons is much shorter than the time limits for the troubleshooting/maintenance lessons. This means that the soldier has to be familiar with CMA diagnostic displays (like the one shown in ***Figure 7***, which indicates a fault in downconverter 10 in rack 2) and error logs.

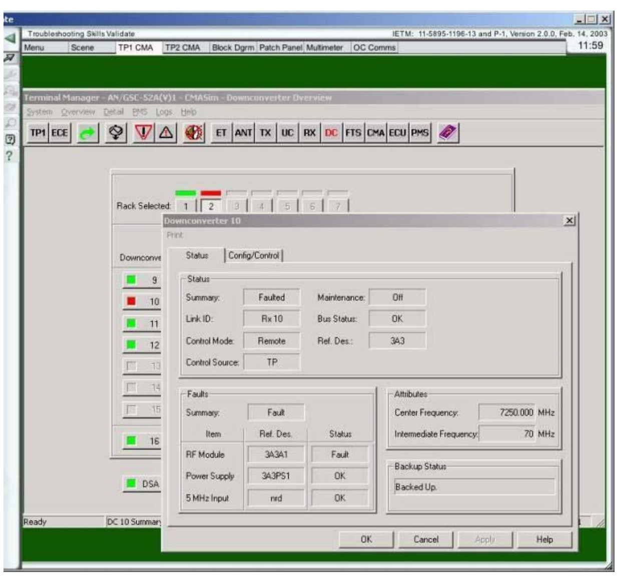

Figure 7. Screen Capture of CMA Fault Display

- **Troubleshooting**. These lessons focus on the diagnosis of faults, the isolation of faulty equipment, and the repair or replacement of the faulty equipment. As noted earlier, the 31S soldiers at GSC-52A ground stations perform both unit maintenance (which involves fault isolation and removal and repair of LRUs), but also DS/GS maintenance, accessing inside the LRUs. This involves use of more sophisticated Test, Maintenance, and Diagnostic Equipment (TMDE). The simulation includes simulation of some of the TMDE that equips a GS-52A ground station. ***Figure 8*** shows a multimeter being used to test connections on a connector in a High-Powered Amplifier (HPA). The troubleshooting scenarios include repair of the HPAs and their high power voltage supplies. ***Figure 9*** shows a step in the repair of an HPA where the front panel has been opened to access the components. These are complex and potentially dangerous procedures to perform on live equipment, so these procedures are not conducted in the schoolhouse or practiced regularly at operational sites.

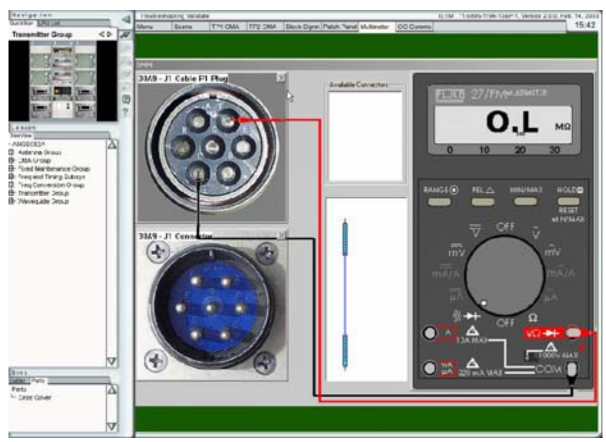

Figure 8. Simulation of TMDE During an HPA Troubleshooting Lesson

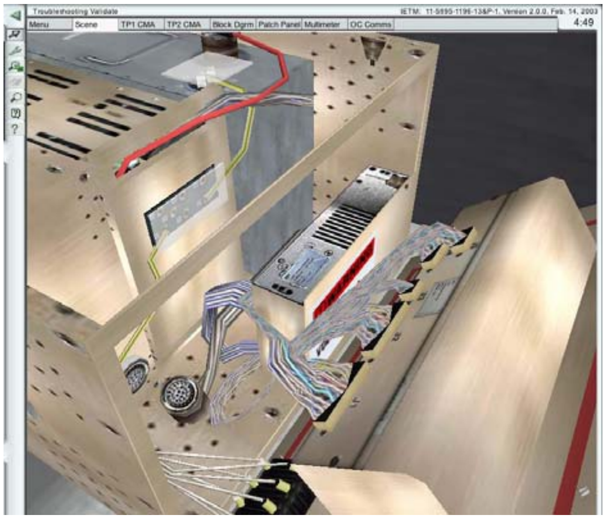

Figure 9. Screen Capture of an HPA Troubleshooting Lesson

LESSONS LEARNED FROM THE AN/GSC-52A TRAINING SIMULATION

The AN/GSC-52A simulation used the CMA operational software as a means of reducing development cost, risk, and time. The difficulties of developing training specific software to accurately mimic the behavior of the CMA operational software was a major consideration in this choice.

Operational and Training Software Interfaces

A key decision in the design of simulations using operational software is the scope of the operational software to be used. For the AN/GSC-52A, the CMA user interface software was reused, but modified so that it was interacting with variables used by the simulation.

The interfaces were sufficiently simple so that connecting the simulation to the CMA code was less expensive than replicating the functionality of the CMA required for training. This CMA software also included the linkage to the IETM, thus the linkage between the simulation and the CMA software also provided the link to the IETM.

Operational and Training Computer Compatibility

If the operational software is used as part of the training simulation, the training computer must provide operating system and middleware functions available on the operational computer. This was initially a problem for the GSC-52A simulation, since the IETM and CMA were implemented on a Windows™ NT 4.0 platform, whereas the simulation was designed for Windows 98™ and Windows 2000™ platform. A new revision of the IETM was released that is compatible with the platforms on which the simulation is supported.

A related issue is that the screen size and resolution of the training computer system must be at least as large as that of the target. The CMA display layouts were altered slightly in order to fit the CMA displays into the screen real estate available on the training computers.

Since the simulation is intimately connected with the operational software, it cannot be used independently for training. Thus the total size of the training system download must include the simulation and the operational software. For example, the size of the AN/GSC-52A IETM is 250 Mbytes, which is 50 times larger than the 5 Mbytes required for downloading all the simulation SCOs.

Substitution of Controls

A key issue for simulations is how to provide methods for the student to interact with the virtual world. The GSC-52A simulation uses a variety of methods to provide these interactions:

- Faceplates in the 3D world were interactive for the activated components. In order to achieve acceptable performance on minimum computer configurations, only a few copies of many components were interactive. However, each lesson included several likely distractors so that in Validate and Practice modes an inexperienced student could start working on the wrong component.
- Like previous UIT simulations, the GC-52A simulation uses high resolution 2D tabs for the CMA displays on the primary and remote consoles.
- Spectrum Analyzers were implemented in the 3D VR environment, rather than using a tab.
- The Multi-Meter was implemented using a 2D tab, reusing technology from previous simulations (McMaster 2002).

FUTURE DIRECTIONS

Many of the issues that result from integration of operational software and simulations will have to be faced as part of the development of training that is embedded in the equipment. From a training perspective, this includes development of training that is directed at sustainment rather than initial training. This is where the power of practice, particularly with rare events or dangerous activities, will be important. From a technical perspective, the problems exposed when interfacing operational software with simulations needs to be investigated further. Issues such as common interface definitions, computer resource and User Interface requirements are prevalent. Also, to the extent possible, the incorporation into the initial design of the operational software the need for training hooks.

This simulations and others being used by the University of Information Technology's Lifelong Learning Center will benefit from quantitative evaluation of student behaviors based on AAR reports (Frank et. al, 2004). Of particular interest will be comparisons of students using the simulation as part of instructor-led classes at Ft. Gordon and AOT and sustainment training in the field.

ACKNOWLEDGEMENTS

These simulations were developed by working very closely with representatives from Ft. Gordon as we explored new ways to train that are appropriate for AOT.

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