

Leveraging Virtualization Technology for Command and Control Systems Training

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Abstract

The North American Aerospace Defense Command (NORAD) and United States Northern Command (USNORTHCOM) (N-NC) crew training has been hindered by an inability to conduct dynamic training and exercises on multiple Command and Control (C2) systems. There was no common simulation injector because of stove-piped acquisitions and legacy interfaces that were incompatible with the Live-Virtual-Constructive Toolkits. The N-NC Joint Training and Exercise Directorate could not afford traditional replication or emulation of all C2 systems and their data sources, nor the inevitable sustainment costs. This paper presents a cost-effective solution to provide dynamic scenario injection into multiple C2 systems: leveraging server and desktop virtualization technology described in previous I/ITSEC papers.

The virtualization process transforms stand-alone systems into functionally equivalent virtual machines (VMs). Server virtualization technology lets multiple VMs run as guests on a single host, and a host can support VMs running different operating systems. This allows entire processing strings, distributed throughout North America, to be converted into VMs on a single server. Because the VMs inherit the fidelity of the actual processors, their outputs are as authentic as the operational systems. These VMs feed processed simulation event data into actual C2 systems or equivalent VMs. Future operational system upgrades can be virtualized and then replace existing VMs without changing this infrastructure.

Desktop virtualization technology allows users to run multiple VMs in separate windows on a common display. N-NC exploited desktop virtualization to simplify the trainee and model operator's workspaces. They can view and manage multiple VMs with one monitor, keyboard and mouse (controlling simulations, lower echelon processing and operator interaction, and viewing C2 workstation displays).

N-NC successfully leveraged server and desktop virtualization to overcome training shortfalls with authentic processing and display of dynamic simulation data. This approach can be used as an archetype for a variety of testing, training, or operational uses.

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BACKGROUND

The North American Aerospace Defense Command (NORAD) and United States Northern Command (USNORTHCOM) (N-NC) Joint Training and Exercise Directorate's Modeling and Simulation Branch has been updating the simulation injection capabilities into legacy and emerging Command and Control (C2) systems. These enhanced simulation capabilities will allow the warfighters to better train for the NORAD and USNORTHCOM missions.*

The NORAD and USNORTHCOM Command Center (N2C2) Training Program consists of four phases: 1) Initial Qualification Training (QT), 2) Mission Qualification Training, 3) Certification, and 4) Continuation Training with NORAD Regions, USNORTHCOM Subordinate, Component, and Supporting Commands, and Interagency partners.

QT for all NORAD mission crews is conducted in an isolated training facility, and includes hands-on interaction with a limited set of the Command's legacy systems. Following QT, the students transition to On-the-Job Training in the operational N2C2 and learn to use their complete set of C2 systems. N2C2 Operations is not staffed with extra crews, which could allow the operators to go to an off-site location for crew proficiency training and exercises. This forces crews to train at their operational workstations during lulls in real-world activities.

Common technical solutions for this training would either be a separate, but co-located, training system or a training capability integrated into the operational system (Simulation-over-Live). Either approach may not interfere unduly with ongoing operations, or require a bigger footprint of displays, keyboards and mice. Figure 1 shows the overall goal of conducting local training and exercises by capitalizing on the Department of Defense Service Modeling and

Simulation Training Toolkits to simulate all of NORAD and USNORTHCOM missions C2 systems (NORAD 2011).

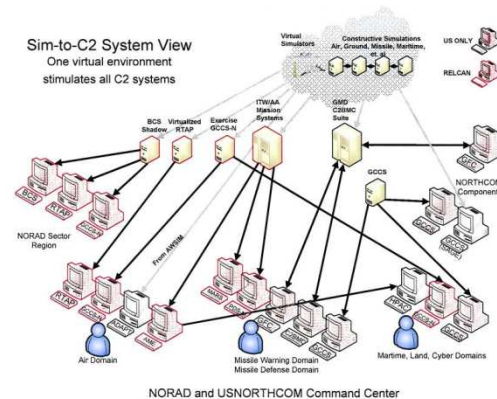


Figure 1. Simulations to N2C2 Missions C2 Systems (N-NC 2010)

The initial focus of the Modeling and Simulation Branch was to upgrade the Air Domain training and exercise capabilities. Their Initial Qualification, Mission Qualification and Certification training historically relied on scenarios for the Air Mission Evolution (AME) C2 system. These scenarios contained events ranging from a hijacked airliner to mass bomber raids. Because of the high cost and lengthy development time, there were a limited set of these scenarios, and they were static – replaying the same events each time. Further, AME was not designed to interface with dynamic injections from any of the Services' Joint Live, Virtual, and Constructive (JLVC) Toolkit simulation capabilities. N2C2 crews regularly documented the lack of dynamic scenarios as a training shortfall.

To address shortfalls, the Modeling and Simulation Branch contracted for changes to the Air Warfare Simulation (AWSIM) Toolkit's database and to output unique messages used by AME. Also, AME's stove-piped communications system required the development of a specialized interface adapter to inject simulation-tagged data. These changes provided a path to conduct local training with dynamic scenarios, and met the objective of "Train as you Fight" by training on the real AME system in the N2C2.

* NORAD mission: to conduct aerospace warning, aerospace control, and maritime warning in the defense of North America. USNORTHCOM mission: partner to conduct homeland defense, civil support, and security cooperation to defend and secure the United States and its interests. (N-NC 2011)

CHANGING C2 SYSTEMS AND NEW CHALLENGES

The initial training enhancement efforts had to be re-evaluated when NORAD changed the priority of Air Domain C2 systems in 2011. AME went from primary, and almost exclusive use, to a tertiary role. The other two higher priority C2 systems are the Remote Tactical Air Picture (RTAP) and Global Command and Control System (GCCS). Operationally, the source of data to all three of these C2 systems is from the Battle Control Systems (BCS), located at the four NORAD Sectors in Alaska, Canada, Western US, and Eastern US. The basic source of the data did not change, but the crews were directed to use different systems and displays to conduct their missions. The inability to locally stimulate these systems with scenario data became a significant training limitation in both the IQT facility and N2C2.

One of the new systems is the Remote Tactical Air Picture (RTAP). This C2 system provides NORAD and USNORTHCOM Headquarters with a more detailed and timely view of tactical air events. The need for a tactical view is because of the post-9/11 homeland defense missions. Domestic events (i.e., hijacking or entering restricted airspace) often have shorter timelines, compared to strategic bomber attack by long-range aircraft. However, RTAP cannot accept local injection of simulation-tagged scenario data and is too complex to emulate. The option to purchase a separate training suite was cost prohibitive, and simply could not fit into the existing server room.

The second priority suite of C2 tools includes Global Command and Control System (GCCS), its Integrated C4I System Framework (ICSF) display client, and an associated Track of Interest (TOI) Tracker. GCCS is the Common Operational Picture and is used to share data with other Combatant Commanders. TOI Tracker extracts some information from the GCCS server database to populate a new “decision support” information display.

With re-prioritization, the new challenge was to provide realistic, dynamic training with events synchronously delivered to these three C2 systems – while constrained to the same operator workstation footprint in the command center.

The Modeling and Simulation Branch met this challenge by taking advantage of the common data source, BCS. We shifted away from AWSIM emulating the inputs into the AME C2 systems.

Instead, we focused on using JLVK Toolkit to stimulate a BCS with simulation data, and sending outputs from its processing into our systems. With this approach, the BCS processing and outputs would be authentic, and BCS’s simulation-tagged outputs become the inputs to RTAP, GCCS and AME.

To afford the proposed authentic processing, we exploited server and desktop virtualization technologies. Server virtualization provided a way to basically replicate dozens of separate systems onto a set of servers that fit into half a rack of equipment. Desktop virtualization enabled us to display the multiple C2 training system views on a single, shared display – much like the “windowed views” of several applications or documents on a personal computer.

VIRTUALIZATION TECHNOLOGY

There are numerous white papers, case studies, and vendor descriptions of server and desktop virtualization technology. Virtualization, and some of its benefits and limitations, was described in the I/ITSEC 2011 *Software for the Rest of Us* session’s “Next Generation of Distributed Training utilizing SOA, Cloud Computing, and Virtualization” (Lanman, J.T., Horvath, S.D., Linos, P.K. 2011).

Server virtualization software can be used to transform or “virtualize” the hardware resources of a computer to create a fully functional virtual machine that can run its own operating system and applications just like a “real” computer. Virtualization works by inserting a thin layer of software, a “hypervisor,” directly on the virtualization server hardware to translate the processing needs of the virtual machine. The leveraging aspect of virtualization is that the hypervisor can manage multiple VM guests running concurrently on a single physical server. It allocates hardware resources dynamically and transparently so each virtual machine is essentially self-contained, eliminating potential conflicts. Another feature of this isolation is that the hypervisor can interface with VMs running different operating systems, such as Windows and Linux. With server virtualization, multiple VMs with different operating systems and applications can run at the same time on a single server or spread across a pool of servers, with each VM having access to the resources it needs when it needs them. (VMWare 2012)

It is important to note that server virtualization is about consolidating the processing of multiple machines onto a server – it does not include the

separate monitors, keyboards, mice and other external components. An exception to this is the virtualization of network switches. Virtualized switches allow VMs that would normally be interconnected on a local or wide area network to be hooked together internally on the same physical server.

Also, because the hypervisor isolates the virtual machines from the physical hardware, we are anticipating an easier upgrade to the next major BCS software release than the actual operational systems. The next BCS version requires all the physical computers to be upgraded to a newer generation of servers, whereas our architecture should not require hardware upgrades.

The two hypervisor licenses we used were from VMWare and Red Hat. VMWare was chosen because of its industry-leading role and product maturity. Red Hat provided cost-effective licensing for the majority of systems we were targeting to become VMs. (Red Hat Enterprise Linux Advanced Platform license allows an unlimited number of virtual guests per host server to run Red Hat as their operating system.) (Red Hat 2009)

For our training and exercise use, we needed to create an end-to-end string of virtual machines that represented everything from the stimulus, through the Sector and local C2 mission processing, and on to the crews' client or workstations, as shown in Figure 2. The final stage was to allow crews to see and control the client VM, since unlike a physical PC, virtual machines do not have direct connection to a keyboard, display video or mouse (KVM).

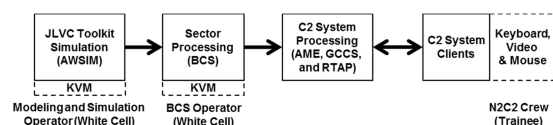


Figure 2. End-to-end String and Participants

Viewing a virtual machine's display presented a different set of challenges. Desktop virtualization provides several techniques that show the display, or displays of multiple VMs. Thin clients act as "dumb terminals" allowing the user to have keyboard and mouse interaction with one or more VMs while showing their individual displays in separate windows on a common monitor. Alternatively, the user may view different VMs through a browser, such as Internet Explorer. Display virtualization allows the user to run several VMs in parallel – taking control of any individual VM by clicking

inside its window; just as internet users view and interact with several web sites in different tabs.

TRAINING AND EXERCISE ARCHITECTURE COMPONENTS

As shown in Figure 2, the dynamic stimulus in our architecture is a virtualized AWSIM from the JLVC Toolkit. This gives the capability to inject the two necessary types of scenario data into a virtual BCS. One of the data feeds from AWSIM is synthetic radar data to – simulating radar data from the Federal Aviation Administration, Transport Canada, or the U.S. or Canadian military. The other type is Tactical Data Link (TADIL) information, representing data from military airborne warning systems or interceptor aircraft.

The virtualized BCS is made up of components normally deployed on several single-purpose computers, as shown in Figure 3. (Thales-Raytheon Systems Company LLC 2008) At the NORAD Sectors, the main processing is by the BCS Sentry Real-Time server. Dozens of separate operator workstations are used to perform tasks such as surveillance and interceptor control. For the training system, we virtualized the Sentry Real-Time server and two of the operator workstations, and connected them on their own internal network. A virtualized RTAP server replicates the physical version of a Sector BCS's new RTAP server. One other necessary BCS component is a protocol translator for changing AWSIM radar data from a Common Digitizer-2 (CD-2) format into BCS's internal ASTERIX format.

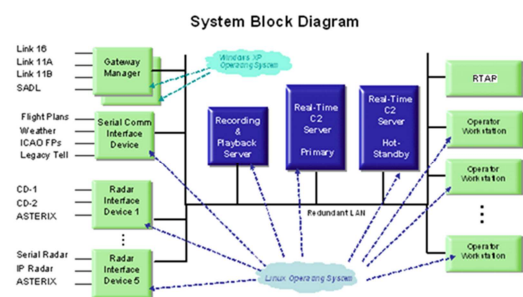


Figure 3. BCS Block Diagram with RTAP Server

VMs are basically files. Creating a duplicate VM is as simple as duplicating the file, and giving it a unique VM name, network name and IP address. So, creating the second operator workstations mentioned above was a relatively simple duplication task. All of

these BCS components run on VMs with Red Hat Linux as the Operating System.

Because the virtual AWSIM and virtual BCS components are integrated onto a single virtualization server, an internal network switch connection replaces long-haul communications. This direct connection is functionally equivalent to the real-world's multiple communications interface boxes, crypto gear and circuits.

The output from the virtual BCS is also locally available on internal networks on the virtualized platform. This eliminated the need for more external communications boxes from the BCS RTAP directly to the virtualized receiving RTAP Web Server. However, the other two receiving systems, AME and GCCS, needed minor interface adaptors to complete their respective connections.

The virtualized RTAP, representing the primary C2 system used at the Headquarters, is also made up of multiple components. The real-world system has an RTAP Web Servers that normally interface long-haul to the RTAP servers at the NORAD Sectors. This Web Server pushes data to the Operators' RTAP Workstations. In our training and exercise environment, the Web Server and all the RTAP Workstations were converted into a set of virtual machines on their own private network switch. As noted above, creating eight RTAP Workstations was relatively easy; duplicating the RWS1 Virtual machine files, renaming them RWS2 through RWS8, and assigning each a unique network name and IP addresses.

The second output from our virtual BCS is the TADIL data to GCCS. This data stream is handled somewhat differently from the others because we chose to re-use a separate hardware platform for the GCCS server. The GCCS server was not virtualized because the commercial virtualization industry did not have a hypervisor for older Sun Microsystems hardware. The server was essentially "no cost" - basically pulled out of the recycling bin with GCCS software re-installed. Also, the TADIL interface from BCS to GCCS needed a minor format change. The reformatting is done using a Common Boundary System (CBS) GOTS tool that normally runs on its own stand-alone computer. The CBS application is installed on a virtualized version of a generic Windows PC.

Operationally, the ICSF clients that display GCCS TADIL track data are normally individual PCs. In our

architecture the eight clients were converted to VMs running a Windows OS with the ICSF software application. Because the ICSF clients are on the virtual server, we have another external network connection from the separate, physical GCCS server back into the virtualization server. The same external connection allows TOI Tracker to access the GCCS database.

The third output from the virtual BCS is data to AME. Because of strict limitations on injecting simulation data into AME, that data stream is converted to a special "Service Oriented Scenario Injector" format. This reformatting is also done by the same Common Boundary System tool.

For a more robust training capability, we chose to provide the capability to exercise with air tracks flying from Sector to Sector. This allows crews to practice their "Cross-Border Operations" procedures. This necessitated creating three more complete sets of virtual BCS systems, so we could model all four NORAD Sectors. The replication task was somewhat more difficult than cloning individual VMs because of Sector-specific naming data imbedded inside the BCS subsystem component adaptation files.

The expanded architecture (only showing two of the four virtual BCS systems) is depicted in Figure 4. A modification to AWSIM was needed in areas of overlapping radar coverage to insure that synthetic radar data was sent to both affected BCSs. Note that the adapters between the individual virtual BCS outputs to GCCS and AME also serve as consolidation nodes for combining outputs from the separate BCSs into merged inputs to the C2 systems. The adapters to AME and GCCS were combined into a single Windows-based virtual machine along with the TOI Tracker application, and labeled "Common Boundary System" in Figure 4.

The virtualized systems described above all reside in the server room. But these virtual machines do not have direct connections to displays. Students in the Qualification Trainer and crews in the N2C2 need to "see" the simulate event data. Additionally, the Modeling and Simulation Operator needs to "see" the AWSIM VM in order to control the dynamic scenario inputs. A "White Cell" player needs to "see" BCS Workstations to act as the BCS Operator and execute essential actions in reaction to an event. We used a combination of two technical solutions for viewing the virtual machines; installing new thin clients, and re-using Internet Explorer on existing workstations.

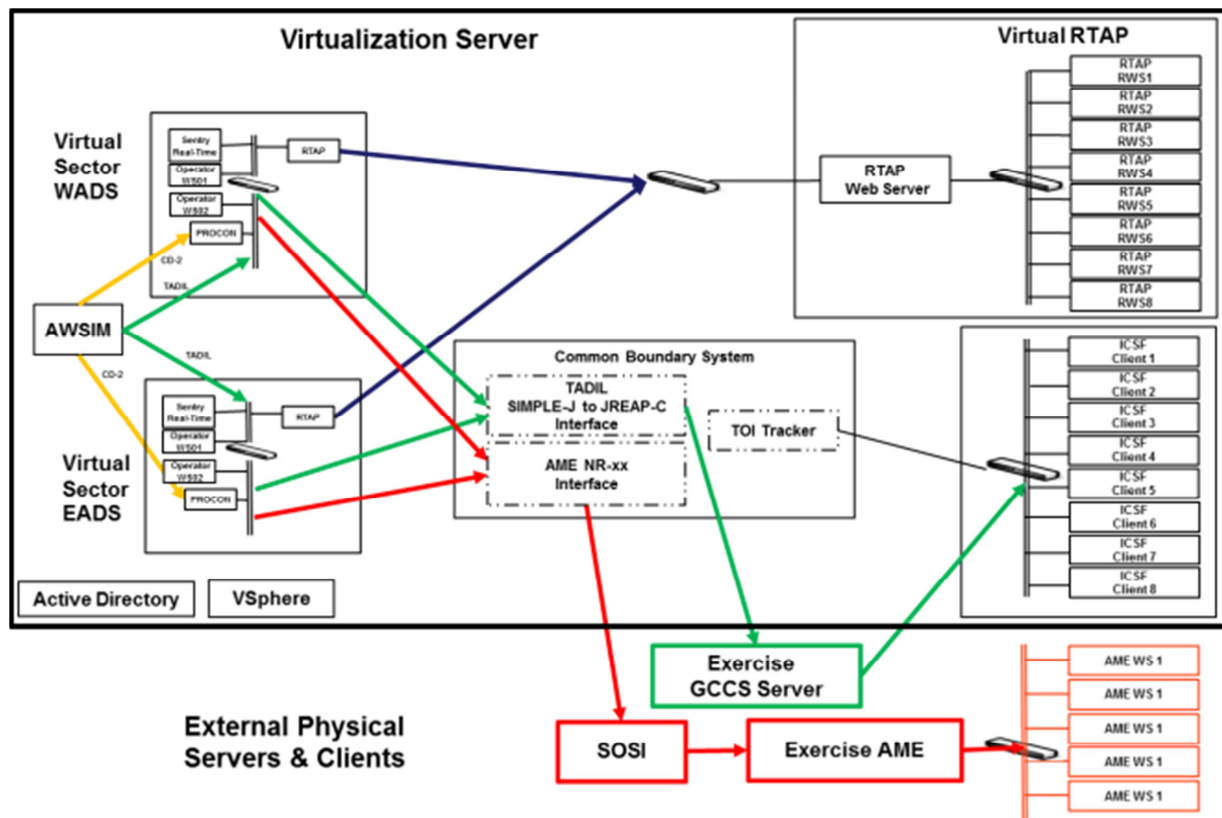


Figure 4. Training and Exercise Virtual and Physical Architecture

DEPLOYMENT AND USES

There are three virtualized Air Domain training and exercise capabilities; at the NORAD and USNORTHCOM Command Center, the Qualification Trainer, and the Canadian Forces Air Warfare Centre.

The N2C2 Air Domain training capability is integrated into the operational command center. This imposes a limitation not to interfere with monitoring real-world operations, and constrains the display of the training/exercise information. The deployment reuses the existing AME exercise capability and its display. RTAP, ICSF and TOI Tracker are “windows” on a single monitor driven by a new thin client. Figure 5 shows the AWSIM Operator driving scenario data into the virtual BCS, then on to AME for processing and display. In parallel the virtual BCS sends data to RTAP and GCCS and their respective displays.



Figure 5. Scenario Injection through to N2C2 Operator Displays

The Qualification Trainer has a full end-to-end capability to stimulate the RTAP, GCCS and AME C2 systems for hands-on training. The QT's systems were intentionally designed to be isolated and have no capability to connect to other operational systems or networks. There is no competition for space on their display because there is no requirement for students to concurrently monitor real-world operations. The three C2 system views can be spread across several monitors through a browser on the existing AME workstation and a new thin client.

The Canadian Air Warfare Center utilizes a scaled back version of the training/exercise capability

because they are only required to support the single Canadian Sector, rather than the four Sectors that supply data to NORAD Headquarters. Their system can function as both a training/exercise tool on the Canadian Forces Experimentation Network, or as a laboratory and development suite.

SAVINGS

An “apples-to-apples” savings comparison to acquiring a set of equivalent environments on physical systems could not be easily estimated. Virtualization gave us the additional flexibility to easily expand to a full breadth and depth to simulate four NORAD Sectors. Our training and exercise environment can dynamically stimulate the three C2 systems. At the low end, the costs in Table 1 show a baseline configuration with eight clients. This may not be representative of other potential virtualization activities because the principle software components and some hardware were government off-the-shelf (GOTS) software or government-furnished equipment (GFE). The costs are conservatively a factor of ten lower than estimates for a comparable version if built on separate physical servers and clients.

Table 1. QT Facility H/W and S/W Costs

Item	Unit Cost	Number	Total
Dell PowerEdge R710	\$ 8,387	3	\$ 25,161
Red Hat Enterprise Virtualization for Servers	\$ 499	4	\$ 1,996
Red Hat Enterprise Virtualization for Desktops	\$ 375	1	\$ 375
Red Hat Enterprise Linux (RHEL) Standard	\$ 1,999	2	\$ 3,998
VMware vSphere Essentials	\$ 611	1	\$ 611
Windows 2003 Server	\$ 150	1	\$ 150
Cisco SF300-24 Switch	\$ 215	2	\$ 430
HP 5740 Thin Client	\$ 550	8	\$ 4,400
Total			\$ 32,782
GCCS-J ICSF Client S/W (Win OS)	GOTS	8	
Common Boundary System S/W (Win OS)	GOTS	1	
BCS S/W components - NORAD Sector (RHEL OS)	GOTS	4	
RTAP S/W components - NORAD HQ (RHEL OS)	GOTS	1	
AWSIM S/W (RHEL OS)	GOTS	1	
TOI Tracker (Win 2003 ServerOS)	GOTS	1	
Sun V240 GCCS Server (Surplus)	GFE	1	< \$1000
Rack (Surplus)	GFE	1	< \$1500
Misc H/W - Cables, tie downs	GFE		< \$80

An often asked question regarding server virtualization is how many physical systems can be run as virtual machines on a server. There are numerous variables that have significant influence (processor cores/socket counts and speed, RAM, and disk size/spindle speed), in addition to the operator’s actual utilization and workload demands.

We contracted with the AME developer to conduct a virtualization study and make enhancements to the QT facility. As part of the study, they did some quantitative analyses on the performance of physical

systems versus virtualized machines running the same applications and under the same loads and operator interactions. Table 2 shows the density expectations if VMs ran on platforms approximately equivalent to those that hosted the stand-alone applications and workstation functionalities. The data shows an ability to host twenty times as many virtual application servers or ten times the number of virtual workstations – a considerable savings of equipment costs and associated power, HVAC, and rack space.

Table 2. VM Performance and Capacity Analysis

Application Server			Thick Client Workstation		
	Physical	Virtual		Physical	Virtual
Peak CPU	3072 Mhz 24%	1836 Mhz 17%	Peak CPU	1175.2 Mhz 13%	4374 Mhz 41%
Average CPU	1408 Mhz 11%	894.7 Mhz 8%	Average CPU	723.2 Mhz 8%	2129.9 Mhz 20%
Expected Density	1	~20 VMs	Expected Density	1	~10 VMs

Expected Density assumes 40% CPU reserved for overhead and future growth

Expected Density assumes 40% CPU reserved for overhead and future growth
** Increase in Virtual WS CPU is due to overhead of processing PCoIP for remote display

A significant impact in most computing environments is the cost, time and effort associated with Information Assurance. As noted in a previous I/ITSEC paper, “The largest challenge affecting the functionality of SOA, cloud computing, and virtualization is security. Security practices are necessary in order to protect systems from viruses and data leakage; however, security degrades system performance.” (Lanman et al.)

With virtualization technology, the IA burden can be reduced or simplified. AWSIM is GOTS software, and came secured with a patch from the Air Force and a Security Compliance Guide for the necessary manual steps. The ICSF clients were also GOTS, with lock-down procedures integrated into the installation procedures. Once one ICSF client was created, the duplicates inherited the IA lock-down profile. In the case of the software for the BCS and RTAP components, they were considered GOTS under agreement with the Prime Contractor, Thales Raytheon. The BCS components took considerable effort to lock-down. However, the virtual RTAP machines inherited a locked-down IA profile from its physical twin. The Common Boundary System was GOTS, and was installed as an application on a locked-down Windows VM.

The thin clients were left as pre-configured from the manufacturer since they always return to that state after being powered down. The only changes were to install the latest patch version of Adobe Flash

Player™, assign a fixed IP address, and new Username and Password.

SUMMARY

NORAD and USNORTHCOM crew training has historically been hindered by an inability to conduct dynamic training and exercises on all of their Command and Control systems. The Joint Training and Exercise Directorate had to redirect its training and exercise enhancement approach when N-NC changed the priority of C2 systems used to conduct the missions.

We leveraged server and desktop virtualization technology to create an affordable virtual environment mimicking the operational systems and crew's workstations. The server virtualization process created functionally equivalent virtual machines with the authentic end-to-end processing and message exchanges.

Desktop virtualization technology allowed the crews to view and manage multiple client VMs without significantly affecting their existing workspace. This enabled the Air Domain crews to "Train as you Fight."

The specifics detailed in this paper describe the savings N-NC realized in overcoming C2 system training shortfalls. In general, the versatility of virtualization can provide similar savings for other operational, testing, training, or office uses.

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