Cloud Full of Predators: Virtualizing Remote Pilot Aircraft for Constructed Training Exercises

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ABSTRACT

For Air Force Special Operations Command, the availability of Remotely Piloted Aircraft (RPA) virtual simulation capabilities to augment Special Operations Forces (SOF) training is of primary interest. AFSOC relies on the Multiple Unified Simulation Environment/Air Force Synthetic Environment for Reconnaissance and Surveillance (MUSE/AFSERS), the DoD flight simulation training system for many RPAs, airborne platforms, and applications. In the ever-expanding demand for realistic training, moving this RPA simulation to cloud based architecture is significant – having the ability to spin up and down, capacity to meet mission needs in a cost-effective manner.

The Air Force teamed with the Army's Joint Technical Center for Systems Integration Lab (JTC-SIL) and Industry to address Operational Training and Test Infrastructure shortfalls with an extensible cloud-based infrastructure. The project objectives included cloud enabling MUSE/AFSERS components; performance evaluations; cost assessments and addressing cybersecurity credentials to support Combat Air Operations Center training.

The development team provisions MUSE/AFSERS components as a service so end users can self-configure based on training needs through decoupled state storage and dynamic, automated computing provisioning. Critical data needs, mission configuration parameters, and terrain files for simulation analytics are provided in a secure cloud repository. There are dynamic cloud resources, tailored and on-demand graphics, and processing requirements execution. Files load through secured streaming connections for end users, federation participants, and cloud resources.

The team built an initial capability to investigate, validate cost, technical execution and determine a path to long-term adoption. The investigation included DoD Cloud Hosting environments, networking requirements, and a roadmap to SIPRNET utilization. The findings revealed cloud-based infrastructure will standardize components; reduce exercise cost, reduce IT footprint and subject matter expertise, and increase accessibility and scalability, thereby providing substantial cost avoidance with improved warfighter training and readiness.

ABOUT THE AUTHORS

Dr. Campbell-Wynn currently serves as a Modeling and Simulation Technology advisor to the Air Force Agency for Modeling and Simulation (AFAMS). In this role, she coordinates with Air Force MAJCOMs to capture training requirements for modeling and simulation capabilities. She collaborates within the services, industry and academia in identifying potential technological solutions, policy creation or implementations that address the identified requirements. Prior assignments include Simulation Training and Instrumentation Command, now Program Executive Office Simulation Training and Instrumentation as a Chief Information Officer (CIO), Deputy CIO, and Information Technology Program Manager. Special assignments include serving as Program Analysts at Army Material Command, Army Modeling and Simulation Office, International Defense Cooperation Office, American Embassy, Paris, France. She served as a technologist with the Information System Command. Dr. Campbell-Wynn has served as an USAF advisor to the AF Mentor Protégé' program to educate and influence the teaming of small and large business interested in modeling and simulation. Education includes a Bachelor of Business Administration, Texas A&M, Masters of Business Administration, Florida Institute of Technology. Masters of Science in Information Resources Management, Syracuse University, Masters and Doctorate of Modeling and Simulation, University of Central Florida, CIO certification, National Defense University.

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BACKGROUND

AFAMS teamed with the Air Force Life Cycle Management Center/Weapons Sensors (AFLCMC/WNS), JTC-SIL and industry partner, Trek10 to address a critical shortfall in the Department of Defense; the availability of virtual simulated Remote Piloted Aircraft (RPA) in the absence of real-world systems in training. The Air Force Special Operations Command (AFSOC) was clearly successful in identifying their mission need in obtaining RPA capability in support of their SOF training requirements.

The Multiple Unified Simulation Environment/Air Force Synthetic Environment for Reconnaissance and Surveillance (MUSE/AFSERS) is the DoD flight simulation/training system of choice for many Unmanned Aircraft Systems (UAS), RPA, and airborne platforms. It is currently used by all Services and most unified commands simulating MQ-1, MQ-9, RQ-4, MQ-1C, M/RQ-5, RQ-7, national and commercial satellite systems, P-3, E-8 and the U-2 during warfighting exercises. The capability provides National Imagery Transmission Format (NITF) information for simulated data collection systems, supporting PED training. The AFSERS also provides Full Motion Video (FMV) and is used as a mission rehearsal tool for current, on-going military combat operations. It is a key training simulation for both the Air Force and the Army, is widely distributed, and used frequently. The current setup for its use is highly siloed and requires significant time and expertise to maintain.

A Phase II Small Business Innovation Research (SBIR) initiative provided the opportunity to migrate the AFSERS simulation infrastructure to a cloud environment, evaluate its performance and perform cost analysis. The main goals in this project were to evaluate cloud capabilities, host MUSE/AFSERS in a cloud infrastructure, evaluates its performance, provide the appropriate authority to operate credentials and address total cost of ownership. This paper addresses the methodology used for the design and development, cloud analysis, capabilities delivered, cost comparisons, findings on total cost of ownership and recommendations for operationalizing the capability.

METHODOLOGY

The government leveraged work from the previous Phase I SBIR. Phase I objectives included establishing a roadmap for migration of a simulation ecosystem to the cloud and identifying a simulation that would act as an initial migration candidate. Through investigation and evaluation, MUSE/AFSERS was identified as an ideal candidate for cloud migration.

The team coordinated with AFSOC/A3 and the USAFE/ Air Forces Africa's Warfare Center (UAWC) to gather more specific requirements to design & build against. The 505th Distributed Training Center assisted in the evaluation. The deliverables of this effort are identified below:

- Initial component analysis
- Full requirements & design and development
- Demonstration of an end-to-end working environment, a "minimum viable product"
- Full cost analysis
- Roadmap to Secret Cloud
- Final code, report and single user guide

- Documented results of engagement with other operational groups to obtain feedback of their get hands-on experience using the solution

DESIGN AND DEVELOPMENT

The core components required for an AFSERS simulation were identified. These components can be described in four main categories: application components, network & external components, storage components, and licensing.
Two diagrams are used to illustrate these concepts. Figure 1 illustrates the core components required to run an AFSERS simulation. Figure 2 highlights the generalized architecture for hosting simulation assets in cloud environments [3].

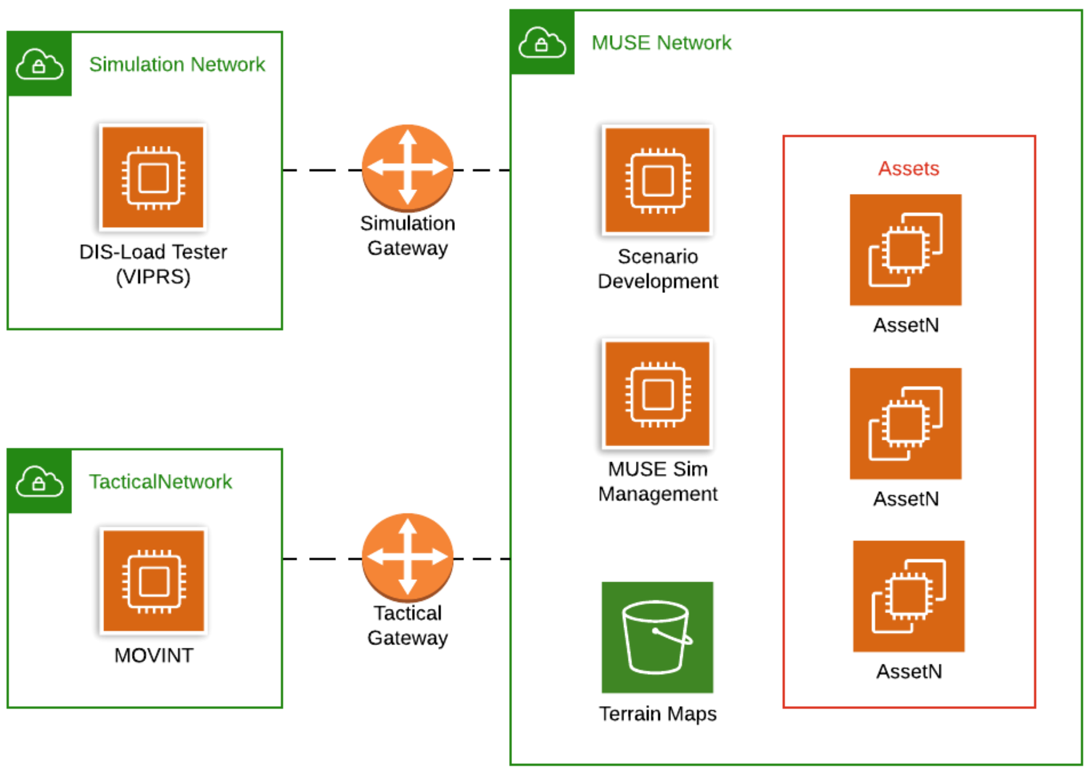

Figure 1. MUSE Simulation Core Components

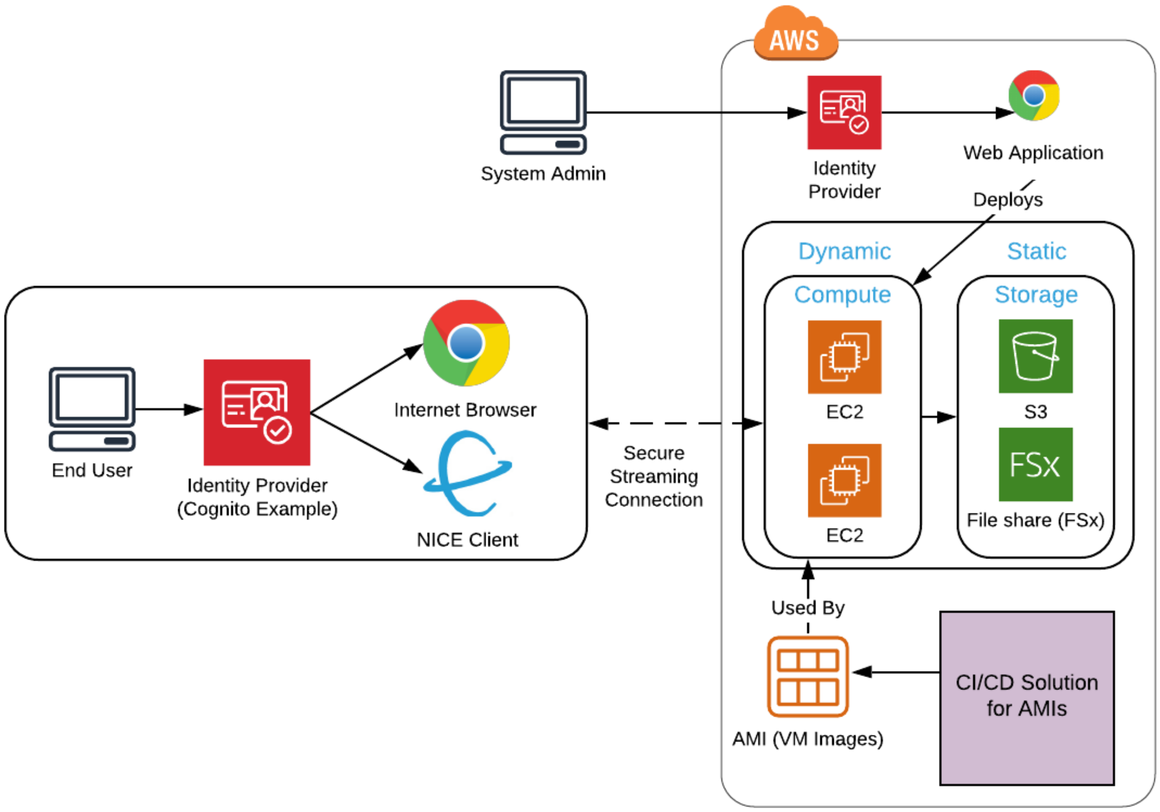

Figure 2. Simulation Asset Cloud Infrastructure

The team built a streaming, cloud-hosted version of MUSE/AFSERS to enhance training/simulation flexibility and reduce costs. Instead of expensive on premise equipment, all of the components are hosted in the cloud and supported by powerful graphics-accelerated computing; operators interact with it through a lightweight local client (laptop). Full compatibility with all MUSE/AFSERS features, Image Generation (IG) support for Virtual Reality Scene Generator (VRSG) and Night Vision Image Generator (NVIG), joystick input, H.264 streaming, and federated messaging with Distributed Interactive Simulation (DIS) is provided. Computing power is on demand, therefore, with a few clicks in a simple web application, users can scale up for large exercises or scale down to zero to reduce cost [3].

OPERATIONS

The MUSE/AFSERS application suite of software is used by a many operators, planners, and analysts to support a variety of training exercises and scenarios. To orchestrate this, the JTC-SIL maintains the suite and provides the required IT support to ensure it is operational for the various exercises performed every year. The IT support required to support the exercises is significant—personnel hours, travel, hardware costs, and opportunity costs all need to be accounted for. JTC-SIL has identified and correlated this overhead to instances of "undifferentiated heavy lifting" that can be reduced with cloud technologies. Amazon coined this term to describe the complex IT overhead and operations companies require to support their business needs. Reducing undifferentiated heavy lifting reduces company IT Total Cost of Ownership (TCO) and transfers IT operations and capital ownership to an established and proven commoditized provider.

An applicable case of this is the need for the JTC-SIL L IT support to ship hardware and personnel support to distant partner nations such as Sweden to support international exercises. Cases involving physically moving IT equipment and supporting personnel become unnecessary in a cloud solution because the application hosting environment can stream the application to various locations as required. This model supports using existing, in-place IT infrastructure to support exercises vice a need to provision and transport servers while providing personnel to build and support the exercise network.

The large overhead associated with the IT support of on-premise systems is not isolated to MUSE/AFSERS, the simulators community, or even the US Air Force. This is a pattern seen across the DoD that the development team believes can be addressed with cloud native technologies. DoD IT support units typically deploy from home station to exercise locations to provide IT support of exercise objectives. Such evolutions occur in phases to synchronize planning, movement, and resources such as personnel, material, and mission supporting elements. Phases include planning, preparation, movement, conduct exercise to achieve mission objectives, recovery to home station for reset and integration back into the equipment maintenance cycle.

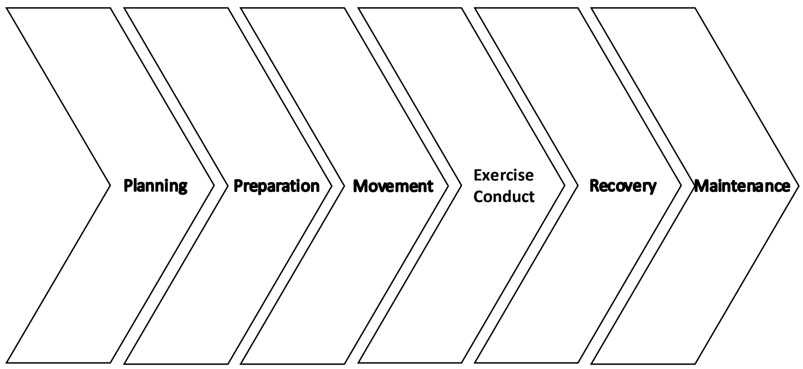

Figure 3. DoD IT Support Phases Figure 1. DoD IT Support Phases

The following section describes an example of an experience with supporting DoD exercises using non-cloud IT equipment. MUSE/AFSERS comparisons are interwoven into the narrative to draw parallels between the two scenarios.

TRAINING EXERCISE SETUP USE CASE

A typical military communications unit based on Okinawa, Japan, deploys “off-island" to provide communications support for DoD units serving in the Far East. Off-island locations include foreign countries and remote islands with little to no supporting infrastructure. Each unit must anticipate and plan for every reasonable, and sometimes unreasonable, contingency while away from home station. Reaching back for needed parts or traveling to a store to craft a viable solution is not an option. Units use what they have on hand, else the affected exercise risks degradation.

The type and quantity of required equipment, operators, and maintainers per mission is a function of the planned network size, exercise requirements, and available on-site transmissions equipment. Some missions require an entire WAN/LAN/voice/data/single channel radio net communications package supporting various classifications and releasability while others require LAN-type connectivity only.

Similarly, the deployment, equipment needs, and setup of MUSE/AFSERS is exercise dependent and will vary between individual exercises and exercise iterations. Size can range between small, “command post” exercises (CPX) where a headquarters staff trains and validates command and control tactics, techniques, and procedures to large-scale exercises such as RED FLAG where aviation units across the Air Force converge to train against advanced tactical and operational problems. Classifications and releasability can vary between controlled, unclassified information (CUI) only to NIPRNET/SIPRNET/TSSCI with a range of coalition releasability. Hardware requirements depend on the exercise size, scenario, and training objectives. A CPX could require a single room with a handful of servers and laptops while RED FLAG requires numerous sites with associated LANs, intersite connectivity, and logistics support. Using the elastic nature of the cloud, we can have the type and quantity of our equipment meet the exact specifications remotely, on-demand. The cloud's relatively unlimited hardware and remote accessibility greatly simplifies the IT exercise support requirements.

In addition to supporting off-island deployments, units addressing United States national security objectives in the Western Pacific operate in a high operational tempo environment. Quite often, units simultaneously plan for one exercise, support the conduct of a second, and recover a third. While a small percentage of personnel and equipment could move sequentially from one exercise to another, the majority of personnel and equipment is dedicated to a single exercise and are unavailable for alternate tasking until completion.

Units tasked with providing communication support begin planning and preparations several months in advance of the exercise start date. Personnel are then assigned to and dedicated to a given planning effort. As plans materialize, equipment and additional personnel are assigned to an exercise and are not available for alternate tasking until the recovery and maintenance phase.

The above highlights a critical resource bottleneck. IT subject matter expertise is a "high demand/low density" resource requiring closely coordinated allocation. Once allocated, committed to an exercise, and sent from home station to a distant site, that subject matter expert (SME) is not available to support another exercise for the duration. The opportunity cost of geographically separated SMEs cost is measured in terms of future or concurrent exercise success in addition to travel and per diem costs to the exercise budget.

Alternatively, remote support with cloud implementation removes unit reliance on over-resourced SME resources. Cloud services provide SME support freeing units from personnel and travel budget restraints. IT exercise support is no longer restrained by the number of qualified personnel available; units will be able to simultaneously plan for one exercise, support the conduct of a second, recover a third, and more.

FINDINGS

There is considerable overhead associated with DoD IT support in general. A TCO analysis of the AFSERS current IT Support process of deploying MUSE/AFSERS applications on-premise was conducted. Three exercise use cases were evaluated. Costs evaluated were provided by JTC-SIL and included onsite SME labor, contractor travel, material shipping, government labor tasks and government material overhead. For all three exercise use cases, the SME associated costs were above 90% of the total costs. The billing information from these exercises made it clear that SME costs are the low-hanging fruit of the "undifferentiated heavy lifting".

TCO ANALYSIS OF CLOUD IMPLEMENTATION

Cloud Cost Calculator

There is a need for large upfront costs to support an exercise, but not with pay-as-you-go model.
Due to the cloud's elastic nature, the cost of running the environment is highly dependent on its usage. Documentation was used to estimate the cost of running the MUSE/AFSERS in the cloud environment.

The first cost estimates in the design phase, were made on sizing. Since the full suite of software is running and the team measured performance, we could more accurately estimate the size of cloud server (AWS EC2) needed to provide adequate performance and other usage variables that affect cost. These were estimates because we all understand that only real-world usage with all the relevant variables around simulation compute needs will give us full confidence in the true cost.

The development team incorporated variables in the documentation that allow one to estimate costs at different usage levels. For example, the "*number of training scenarios"* and the "*average length of training scenario*" variables were adjusted to obtain the following results below in Table 1:

Table 1. Variables and Cost Estimation

Number of Training Scenarios	Average Length of Training Scenarios (Hours)	On Demand Cost (Total)	Compute Savings Plan (Total)
1	24	$112	$98
3	72	$1,004	$882
10	120	$5,580	$4,899

As training/simulation exercises are executed, server infrastructure is spun up and down with a simple interface. Therefore, costs will linearly scale with how many exercises are executed and how long they last.

Three scenarios running an average of 72 hours each (for a total of 216 hours) costs approximately $1,004 per month. The average cost per scenario-hour is $4.08. The initial estimate was based on the On-Demand hourly rate of running EC2 instances. In reality, it is not likely that an AWS environment as mature as this would be using the standard On-Demand hourly rate. Therefore, we have included an additional estimate using a Compute Savings Plan (CSP) hourly rate. There are multiple ways to save on Amazon Web Service (AWS) compute costs by committing to usage; CSP are one of the simplest, but also smallest savings, so a CSP hourly rate was used as an easy first heuristic. More complex savings options such as EC2 Reserved Instances can be layered on in future cost planning exercises.

AFSERS CLOUD IMPLEMENATION APPROXIMATE COSTS

The cost to leverage the Cloud implementation of MUSE/AFSERS is highly dependent on the usage. Thus, the following begins by approximating the TCO of MUSE/AFSERS implementation to support a smaller exercise group relative to those JTC-SIL has traditionally interacted with. From there, the TCO is analyzed from the perspective of the usage requirements of a larger exercise group.

To inform our approximation, the team used averages of the billing information provided by JTC-SIL. The averages are summarized in the Table 2 below:

Table 2. ROM Cost Averages

Service	Cost
Labor	$53,386.20
Travel	$16,341.32
Material & Shipping	$22,700.00
Overhead & Fees	$1,973.12
Total	**$94,400.63**

Cost for exercises classified as small and large are provided in Tables 3 and 4.

Table 3. Small Exercise

Service	**Cost**	**Total**
Labor	($53,386.20 * 0.25) * 0.5	$6,673.28
Travel	($16,341.32 * 0.25) * 0	$0.00
Material & Shipping	($22,700.00 * 0.25) * 0.1	$567.5
Overhead & Fees	($1,973.12 * 0.25) * 1.0	$493.28
Cloud Costs	$1,511.00 * 12	$18,132.00
Security Tooling	$10,000	$10,000
Total		**$35,866.06**

Table 4. Large Exercise

Service	**Cost**	**Total**
Labor	($53,386.20 * 1.25) * 0.5	$33,366.38
Travel	($16,341.32 * 1.25) * 0	$0
Material & Shipping	($22,700.00 * 1.25) * 0.1	$2,837.50
Overhead & Fees	($1,973.12 * 1.25) * 1.0	$2,466.40
Cloud Costs	$30,743 * 12	$368,916.00
Security Tooling	$10,000	$10,000
Total		**$417,586.28**

The cloud implementation of MUSE/AFSERS reduces the TCO through the use of cloud-native technologies in the following ways:

- Scalability of the cloud & economies of scale.
- End-User devices can be implemented with the “Thin Client” paradigm.

- There is no need for large upfront costs.
- Elastic resources are available.
- Automatically upgraded hardware generates no degradation.

CLOUD ONE ANALYSIS

As part of this SBIR effort, the team analyzed the government sponsored CSP, Cloud One. Cloud One's platform-as-a-service (PaaS) model offers an ideal balance of mission application self-management, and best-practices. DISA-approved "guardrails" allow your team to focus on your application instead of spending valuable time managing the hosting environment and underlying infrastructure. [2] Cloud One offers a subset of commercial cloud services that are DISA-approved for Impact Levels (IL) 2, 4, 5 and 6, including:

- Boundary protection service provided by DISA Global Content Delivery Service (GCDS)
- Provides commercial cloud services during ATO attainment
- Cyber Security Service Provider (CSSP) services provided by C5ISR
- Cloud One-provided inheritable security controls and hosting environment ATO
- For most mission applications, approximately 40% of required control can be inherited from Cloud One enclaves.

The team analyzed the application of Cloud One's impact cost. The following are some key takeaways:

- Cloud one does not add costs on top of the AWS costs.
- There are no overhead or entrance fees.
- Hybrid & Standard Migration Plans are available.
- Optional hybrid migration support is estimated at approximately $3200 per month.

In short, team concluded that hosting in Cloud One will not add significant overhead to the TCO of the MUSE/AFSERS. In fact, team reported that it will ultimately reduce the TCO through the inheritance of various controls. Cloud One claims 30% of the controls can be inherited in IL6 workloads [5]. The solution will also reduce the long term TCO of maintaining an Authority to Operate (ATO).

TRAINING BENEFITS

There are several benefits to a cloud-based infrastructure. They include cost efficiency, scalability, common services, increased security, and continuity of services [6]. The MUSE/AFSERS cloud-based infrastructure will provide increased accessibility and availability of the applications to the various operational training exercises and mission rehearsals at a reduced cost. There are times when the existing infrastructure is not used because of the availability of resources to support the events in various areas of the world. Some units do not have the funding to pay for the subject matter expertise and equipment needed to use the capability. In some cases, the technical subject matter expertise may not be available due to other commitments. The capability of the cloud infrastructure will be made available through a centralized service that will contain the latest software and configurations. The latest software versions and the standardization of the product are added benefits to the training community.

Due to the availability of the service via the cloud infrastructure, more frequent training may be considered. During the Joint Event Life Cycle (JELC) planning, training events are documented and prioritized. Some specific events and associated capabilities are sometimes not prioritized high due to availability of resources. The UAS/RPA cloud base infrastructure provides more options for more frequent training.

CHALLENGES

There are a few challenges to note with DoD cloud migration. During this effort, the team was able to communicate with potential users from the 505th Distributed Training Center and the AFSOC Readiness Training Center. These potential users provided valuable feedback from the team that must be considered for a successful migration to this infrastructure. It was noted that it is critical that this capability is always available due to the nature of the exercises that are conducted both within the United States (CONUS) and overseas (OCONUS). Many of the exercises using the simulation and networks are running 24/7. If a commander is overseas in Germany and a server is down, he or she requires the assurance that someone in the states is available to address the problem regardless of the time within the 24 hours. It is costly to support an exercise with thousands of warfighters and downtime is not very tolerable. The system must be stable and the performance acceptable. This includes not only the server but the availability and performance of the network. The supporting infrastructure must be resilient.

The change in mindset for some will have to be different. A director is usually very comfortable with having all of the resources running in their local environment. When it is not physically in their space, he or she has to know that the resources will be available. Considerations to a hybrid infrastructure offering flexibility may be considered.

Additional cost is always a factor to consider. In the case of MUSE/AFSERS there is funding to address the sustainment of the software application. However, cost for the cloud base infrastructure will have to be addressed. We see an overall reduction in cost to use this infrastructure when you consider the traditional costs of training exercise setup and execution, but the implementation plan must include the cloud utilization cost for each center. Currently, the cloud infrastructure cost is not programmed for each center.

RECOMMENDATIONS/FUTURE ACTIVITIES

Actual use at a designated exercise is recommended to obtain additional feedback. Follow on initiatives could address the additional requirements.
The following recommended core activities for future expansion are identified below:

- Certification on the NIPRNet, SIPRNet / AWS Secret Cloud, with continuous ATO.
- Support to distributed exercises on a variety of networks.
- Use as a foundation for a Simulation Migration Foundry, through which many other legacy simulation systems could be migrated to and delivered from elastic cloud environments [4].
- Operationalize this capability across DoD.

CONCLUSION

DoD has an enduring requirement to provide trained RPA operators, planners, and analysts capable of exploiting the full capabilities. The MUSE/AFSERS application provides the modeling and simulation to ensure training support yearly. Cloud hosted solutions offer opportunities to increase operational agility, remove burdensome obstacles to training, and reduce operating costs. Moving to the cloud can centralize updates, provide economies of scale and leverage cheap on-demand compute power that can be spun up and down automatically based on usage.

Today, the IT support required to support the exercises is significant. Personnel hours, travel, hardware costs, and opportunity costs are required regardless of the exercises size and scope. Reducing undifferentiated heavy lifting reduces IT TCO and transfers IT operations and capital ownership to an established and proven commoditized provider. Using the elastic nature of the cloud, supporting units can take advantage of the type and quantity of required equipment to meet the exact specifications remotely, on-demand, and in sync with operational and scenario needs. The cloud's relatively unlimited hardware and remote accessibility greatly simplifies the IT exercise support requirements.

Cloud services reduce SME support thereby freeing units from personnel and travel budget restraints. IT exercise support is no longer restrained by the number of qualified personnel available; units will be able to simultaneously plan for one exercise, support the conduct of a second, recover a third, and more.

ACKNOWLEDGEMENTS

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