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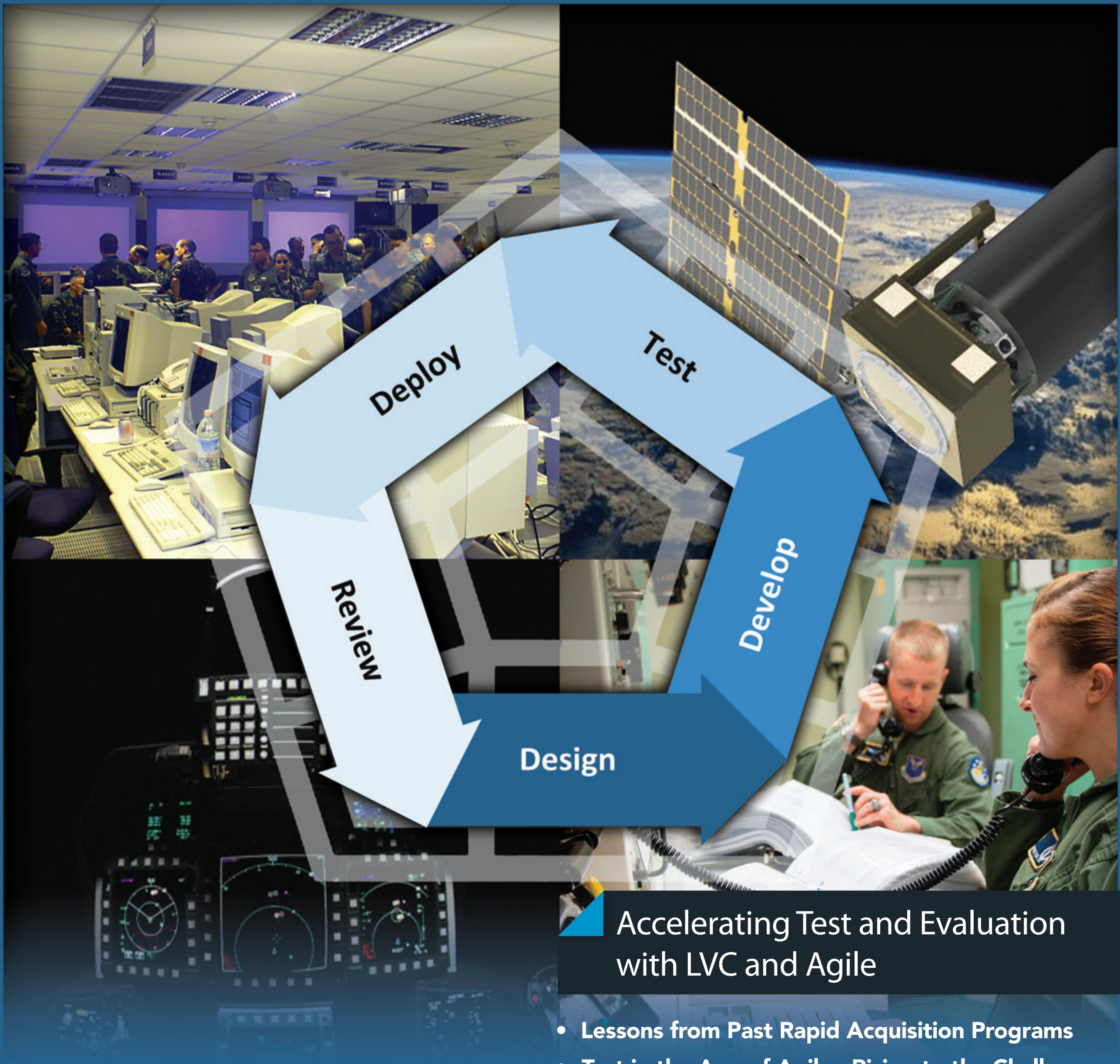
The ITEA Journal of Test and Evaluation



Accelerating Test and Evaluation with LVC and Agile

- **Lessons from Past Rapid Acquisition Programs**
- **Test in the Age of Agile: Rising to the Challenge of Agile Software Development**
- **Self Service Infrastructure Environment for Next Generation High Performance Test and Evaluation**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ON THE COVER:
The cover graphic was developed by Lieutenant Colonel Christopher "Loose" Cannon, Chief, Command and Control Programs, Air Force Test and Evaluation (AF/TE). He joined AF/TE in June 2018, and he previously served as an Air Battle Manager in the E-3 AWACS and the E-8 JSTARS, on the NATO Air Staff, and in a Control and Reporting Center in the United States Air Force theater air control system. Some added photos are from AF.MIL/News/Photos.

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◆ For more than thirty years the International Test and Evaluation Association (ITEA), a 501(c)(3) not-for-profit education organization, has been advancing the exchange of technical, programmatic, and acquisition information among the test and evaluation community. ITEA members come together to learn and share with others from industry, government, and academia who are involved with the development and application of the policies and techniques used to assess effectiveness, reliability, interoperability, and safety of existing, legacy, and future technology-based weapon and non-weapon systems and products throughout their life cycle.

ITEA members embody a broad and diverse set of knowledge, skills, and abilities that span the full spectrum of the test and evaluation profession. All of which is shared with others through *The ITEA Journal of Test and Evaluation*—the industry's premier technical publication for the professional tester—and at ITEA's Annual Symposium, regional workshops, education courses, and local Chapter events. Join the thousands of ITEA members—your peers in the industry—in contributing to *The ITEA Journal of Test and Evaluation* and participating at ITEA events so that you also can benefit from the opportunities to learn from others, share your knowledge, and help advance the T&E industry.

◆ **Subscription Rates for *The ITEA Journal of Test and Evaluation***

The ITEA Journal of Test and Evaluation (ISSN 1054-0229) is published quarterly by the International Test and Evaluation Association (www.itea.org) at 4400 Fair Lakes Court, Suite 104, Fairfax, Virginia 22033-3899. *The ITEA Journal of Test and Evaluation* serves the test and evaluation community as a forum for the presentation and discussion of technically sound knowledge and experience, software and/or hardware tools, Works-in-Progress, new ideas, and emerging fields, research topics, and challenges of interest to test and evaluation professionals, the test and evaluation community, and organizations involved in the test and evaluation community.

- ITEA offers annual membership for individuals, full-time students, and any organization interested in advancing the test and evaluation profession. Annual membership includes a one-year subscription to *The ITEA Journal of Test and Evaluation*.
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- The single-issue cover price for *The ITEA Journal of Test and Evaluation* is $50 ($75 for non-US mailing address)
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  - Print Only - $150 ($275 if located outside of the US); and
  - Print plus Online Access - $225 ($350 if located outside of the US)

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Articles of general interest to ITEA members and *The ITEA Journal of Test and Evaluation* readers are always welcome and a great way to contribute to our industry.

PEER REVIEWED ARTICLES: ITEA members may submit articles designated by the author(s) to be peer reviewed. These peer reviewed articles will be highlighted in *The ITEA Journal* and this new opportunity for authors offers even more value to their published article.

Other articles needed include specialty features, each 2-3 pages long, in contributed articles.

- **Featured Capability** describes unique, innovative capabilities and demonstrates how they support T&E.
- **Historical Perspectives** recall how T&E was performed in the past or a significant test or achievement, often based on personal participation in the "old days" of T&E. A recent article by James S. Welshans, Ed.D. on Operationalizing Cyber Warfare is a great example.
- **Tech Notes** discusses innovative technology that has potential payoff in T&E applications or could have an impact on how T&E is conducted in the future.
- **Cultivating the T&E Workforce** addresses the future of T&E and looks for ways to encourage students to pursue and remain in STEM (Science, Technology, Engineering, and Mathematics) courses and academic majors. This section also welcomes articles on ideas for innovations in professional education for the T&E workforce.
- **Book Reviews** of new books on topics related to T&E and related disciplines.

ARTICLES AND SUBMISSION: Articles of general interest to ITEA members and *The ITEA Journal* readers are always welcome. *The ITEA Journal of Test and Evaluation* offers a forum for sharing knowledge and ideas crucial to our changing T&E workforce. Submit your contributions today to journal@itea.org, attention: Publications Chair. Manuscript guidelines are found at www.itea.org under the "ITEA Journal" then "Submissions" tab.

The ITEA Journal of Test and Evaluation Themes for 2019-2022

Please consider writing an article, share this document with coworkers, and provide feedback on the themes. For all themes in 2019-2022, please check the ITEA website at www.itea.org under the "ITEA Journal" then "Upcoming Issue Themes" tab. – Steve Gordon

Upcoming ITEA Journal Themes

Aligning Modernization of DoD Test Ranges with National Defense Strategy

(Issue 40-3, September 2019)

DoD test ranges need to be modernized in order to adequately test advanced systems in development and current, updated systems designed to perform in future warfighting environments. Our systems must be tested sufficiently in the anticipated environments and scenarios to make sure they are resilient. Unless properly handled or accommodated, environmental encroachment can cause limitations to testing and training; these limitations can include restrictions, degradations, interference, pressures to reduce maneuver space, and increased cost. The science and technology (S&T) research in this area is extensive. Are there lessons learned or success stories in preventing incompatible development near test and training ranges? Papers related to these topics, to developing improved and expanded ranges, and to resolving encroachment issues are requested. Also, papers that discuss ways to complement range testing with gaming or simulation are welcomed. Range challenges will continue to impact test and training ranges, but the limitations can be moderated. Best practices in this area would be of interest to the readers.

(Manuscript deadline: June 2019)

Drowning in Data: How to Gain Timely Information and Knowledge from Data

(Issue 40-4, December 2019)

Digital technology and accelerating improvements to digital technology provide us with the ability to acquire, create, and store data at unprecedented rates and volumes. Literature searches that would have taken days or weeks in the age of library card catalogs now can be accomplished in seconds over the internet. Data, or more generally, information, has become big business, in addition to being the business of T&E. Yet, technological solutions come with their own problems: the immense flow of data from tests has not been met by a commensurate growth in the ability to exploit the data to gain information and knowledge. This theme examines the issues and the potential solutions for the need to extract meaning and value from the mountains of data. Articles are invited on such topics as data acquisition, storage, archiving, access, validation, exploitation, and visualization; data as a service; cloud computing; service-oriented architecture; metadata syntax and semantics; instrumentation; accelerating the process of acquiring data to making a decision; data and sensor fusion; data preservation; distributed and nonrelational databases; and related topics. The theme seeks insights, lessons learned, and success stories of gaining information and knowledge in a timely manner from test data.

(Manuscript deadline: September 2019)

The Right Mix of T&E Infrastructure

(Issue 41-1, March 2020)

Our T&E infrastructure is regularly evaluated for downsizing, improvement, or changes in ownership. The right footprint of T&E infrastructure depends on the tests in the pipeline and future systems in design. How do we know what and how much is necessary? How do we find the right sources of information (who knows?), and how can we search for facilities available nationally and internationally? Can we share government, industry, and university facilities within and across country boundaries? Would this type of sharing cause conflict of interest issues? Will overlap of contractor testing, developmental testing, and operational testing reduce or increase the demand on test infrastructure? Can a shift to earlier developmental testing in representative operational environments and a push for integrated testing reduce the load on test infrastructure?

(Manuscript deadline: December 2019)

Systems Engineering and T&E Synchronization

(Issue 41-2, June 2020)

These activities are part of an integrated, solid T&E process. Systems engineering provides the process and tools to build the right effective products in the best way. Reliability strives to develop a system that is available and suitable for the intended use and resilient to disruption. Life cycle support looks at maintainability

and supportability with long-term ownership costs in mind. Testing makes sure these requirements and others are satisfied by the designed and produced system. Blending these initiatives into an integrated T&E program could help us field the right system for the user. Invited papers could include discussions of success stories, lessons learned, drawbacks, benefits, good intentions gone awry, and alternative views.
(Manuscript deadline: March 2020)

Innovations in Modeling and Simulation (M&S) Use for T&E
(Issue 41-3, September 2020)

M&S allows depiction of places and times where the users of the M&S cannot otherwise go. These battlespaces and times could be in the past, future, or into areas where enemy defenses or other physical barriers prevent immediate travel. In light of this powerful benefit of M&S, there are at least two situations where M&S gives the most benefit in T&E. The first is the reduction of testing cost. Rather than running flight tests or destroying weapons systems, we simulate the activity in the laboratory to determine if the system satisfies the developmental documentation and performance and if the system meets operational effectiveness and suitability. We can then verify performance with much fewer flight tests—saving money by running fewer high-cost live tests. The second is the ability to use M&S to generate operational edge conditions that we cannot create in the live operational environment. We can simulate operational conditions that would be expensive or impossible to create in a physical operational test. Examples could be testing aircraft in lethal environments or after the departure from safe flight or load testing an air traffic control system with more tracks than would be possible in the live operational environment to prove performance resilience requirements.
(Manuscript deadline: June 2020)

T&E for Cyber Security and Readiness
(Issue 41-4, December 2020)

Key information passed through network connections improves the speed and lethality of combat operations; yet, use of networks opens doors to vulnerabilities. Network connections for home computers, smart phones, social media, and entertainment add enjoyment; yet, ease of use often equates to increased ease of misuse and scamming. Systems that support the military, our finances, our health records, and our other personal information must pass risk management, information assurance/security, net readiness, and cyber readiness tests. Yet, these tests, when passed, do not provide 100% assurance of protection. Systems and the networks that connect them are subject to attacks from many sources; however, the goal of the attack is nearly always to take something valuable. Money, personal information, trust, freedom, military information and plans, or intellectual property are often taken with very minimal effort and cost. How much testing is required to provide an acceptable level of risk and enduring protection to expected attacks?
(Manuscript deadline: September 2020)

2020-2021 Themes of *The ITEA Journal of Test and Evaluation*

2021	42-1	March	New Initiatives in Developmental and Integrated T&E
	42-2	June	Training the Future T&E Workforce
	42-3	September	Testing Artificial Intelligence and Collaborative Autonomous Systems
	42-4	December	Success Stories in T&E
2022	43-1	March	Accelerating T&E to the Speed of Need

Accelerating Test and Evaluation with LVC and Agile Workshop

Hosted by the ITEA Central Florida Chapter

Orlando, Florida • September 17-19, 2019
DoubleTree by Hilton Hotel Orlando East-UCF Area

PROGRAM OVERVIEW

Fielding effective, secure systems to warfighters at the speed of need is essential, but this goal is difficult to achieve given that industrial-age acquisition and systems engineering processes, including Test and Evaluation (T&E), do not mesh well with development and use of modern software-intensive systems. Agile software processes that combine acquisition events with developmental and operational testing show promise in decreasing historic timelines. Combining software development (Dev) with built-in information technology security and assured hardware platforms (Sec) with information technology operations (Ops) throughout the DevSecOps software build is also streamlining the delivery of secure software-intensive systems. Finally, increasing the focus on what the warfighter needs now and what is necessary for potential conflicts will provide more usable and effective systems. Other key ideas for improving effectiveness and accelerating this process include early prototyping via modeling, simulation, and gaming; evaluating hardware prototypes; combining test events; the use of Artificial Intelligence to improve data gathering and reporting; and evolutionary program development. Simulation and gaming environments can be used to allow warfighters and testers to evaluate the advantages of system variants and alternative tactics before the hardware and software are finalized.

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William T. Keegan

Acquisition organizations and the capabilities they provide the end user critically depend upon the adequacy of test and evaluation (T&E). This is true for both industry and government. This adequacy includes a skilled and experienced workforce to conduct evaluations, tests, and planning. It also includes the test infrastructure, instrumentation to match systems under test, and a way to manage big data. As we proceed to the 2019 ITEA Annual Symposium, you will see that ITEA has addressed many of these topics over the course of the year.

The necessity of robust developmental test and evaluation prior to approaching anything close to operational test and evaluation is becoming more and more important as systems become more complex. Both industry and government—customer and provider—will need more transparency and open communications in order to clearly demonstrate readiness to proceed past milestones based on the results of testing. The immense tasks associated with growing complexity demand it.

As a result of these pressing needs, and in recognition of the real constraints on resources, *The ITEA Journal* has attempted to address many of these issues with challenging topics and themes for each quarterly issue. These themes cover accelerating test and evaluation with LVC and Agile, modernizing test ranges, big data and how to manage it, and what constitutes the right mix of test infrastructure.

This issue of *The ITEA Journal* has features from Steve Hutchison highlighting the critical importance of T&E, Kevin McGowan describing cyber testing in a rapid DoD acquisition environment, and Eileen Bjorkman discussing the implications of going faster for T&E. Our line-up of technical articles address, in detail, this quarter's theme, "Accelerating Test and Evaluation with LVC and Agile." Lindsay Davis writes about lessons from past acquisition programs; Doug Wickert writes about testing and Agile software development; Chuck Reynolds and Steve Campbell present an interesting piece on self-service infrastructure and next generation high performance T&E; Jeffrey Riemer describes a strategy to prevent delays in range availability; Paul Knight discusses environmental challenges as well as range sustainability, a growing concern across the board in T&E; R. Douglas Flournoy, et al. talk about fast data analytics; and Dave Brown and Dave Bell discuss how the combination of Agile, systems engineering, and independent T&E shows great promise to enhance the development of complex systems.

Further, ITEA has designed an educational program of tutorials, workshops, and symposia tailored to the needs of the workforce: The Test Instrumentation Workshop, and The November 2019 Annual Symposium, which will provide numerous cutting-edge technical tutorials, along with plenary sessions and breakout sessions that address topics related to the theme of T&E challenges associated with global threats. We will also present a specially tailored workshop in September, Accelerating Test and Evaluation with LVC and Agile, which follows up on this issue of *The ITEA Journal*.

I would like to thank all of the authors for their technical articles, contributors to guest editorials, and all the senior leaders, government and industry, who support ITEA as a way to advance best practices in test and evaluation. Your support has a long-lasting impact on the development of T&E professionals, and others in the acquisition community who learn a great deal at our venues. Lastly, I would like to thank all volunteers who supported the Test Instrumentation Workshop, which took place just prior to this publication. Well done all!

William T. Keegan

The ITEA Journal of Test and Evaluation 2019; 40: 72-73

The theme for this issue is **"Accelerating Test and Evaluation with LVC and Agile,"** and the issue includes the *President's Corner*, two *Guest Editorials*, an *Inside the Beltway*, a feature discussing the upcoming 2019 International Test and Evaluation Association (ITEA) Symposium, and seven technical articles. The term "LVC" has many meanings depending on who uses it, what is the purpose of the discussion, and who is trying to understand it. For this purpose, we want to promote a discussion of the ways that a mix of Live (humans operating actual systems), Virtual (humans operating in simulators), and Constructive (humans controlling computer simulations) can be used to facilitate system trade-space studies, perform evaluations of proposed systems, or compare current to proposed systems in simulated combat environments, as just some examples.

President's Corner, written by William Keegan, President of the Board of Directors for ITEA, covers the state of the association, ITEA accomplishments, and upcoming ITEA events.

Our first *Guest Editorial* is "Sometimes a Picture *Is* Worth a Thousand Words" written by Steve Hutchison, Ph.D., as a reminder of the critical importance of test and evaluation (T&E). Thorough testing helps make sure that systems work when operators expect, want, and need them.

Our second *Guest Editorial* is "Cyber Testing in a Rapid DoD Acquisition Environment" from Kevin McGowan. He states that the desire to use Agile methods and rapid prototyping acquisition strategies presents some challenges to the cyber test community. He describes several ways to fully assess and incorporate cyber survivability, even as acquisition and T&E are accelerated, including continuous two-way communication and cooperation between developers, testers, and customers.

For our *Inside the Beltway* feature, "Going Faster: Implications for Test and Evaluation," Eileen Bjorkman, Ph.D., explains that regardless of how we label it, DoD acquisition programs are trending toward more rapid fielding and accepting more risk. She also explains that the systems and techniques used to test new systems must be in place before the new systems can be accelerated through T&E.

Our next feature, "Let's Meet in Kauai One More Time," is a description of the plans for the 2019 Symposium. We will be holding this Symposium in Kauai for a third time. With 11 military bases in Hawaii, including the largest instrumented multi-environment training and test range in the world on Kauai, this will be an ideal location to hear feedback from warfighters and presentations by acquisition and T&E professionals. This article describes the Symposium's Technical Program and outlines the basic sequence of events. More information will be provided on the ITEA website, in regular electronic mail announcements, and in a final article in the September issue.

Our first of seven technical articles, "Lessons from Past Rapid Acquisition Programs," written by Lindsey Davis, Ph.D., summarizes the lessons learned from previous rapid acquisition programs in order to help establish recommended best practices for future programs. She provides case studies to illustrate some of the lessons learned and some best practices that may improve the chances of successful rapid fielding.

The second technical article in this issue, "Test in the Age of Agile: Rising to the Challenge of Agile Software Development," written by Colonel Douglas Wickert, Ph.D., states that adapting Agile methods for military systems requires careful consideration and changes to traditional T&E methods. He presents the unique challenges related to testing in an Agile process and continuous development frameworks. We must ensure that speed is vectored in a direction that serves the needs of warfighters.

For our next article, "Self Service Infrastructure Environment for Next Generation High Performance Test and Evaluation (T&E)," by Chuck Reynolds and Steve Campbell, the authors explain a growing trend of high-performance computing centers using self-service portals to schedule, reserve, configure, and deliver solutions. The authors describe their proposed solutions to providing T&E as a self-service high performance computing solution.

In our fourth technical article, "A New Strategy for Funding Test and Evaluation Range Infrastructure," Jeffrey Riemer, Ph.D., describes an alternative funding strategy that can prevent delays in range availability and reduce the risk of not having the necessary T&E infrastructure when needed. The author's plan leverages the concept or recoupment, and explains how this can be a win-win for program offices and the T&E ranges.

In the fifth technical article, "Environmental Challenges and Range Sustainability," Paul Knight addresses the challenges faced by Department of Defense (DoD) test ranges, and he explains the best practices used by ranges to mitigate the impacts of the challenges. With proactive engagement and long-term commitment to stay ahead of the challenges, ranges can be sustained and made ready for accelerated T&E.

For the sixth article, R. Douglas Flournoy, et al., present "StreamServer for Fast Data Analytics" to highlight a class of efficient processing methods to analyze the contents of high velocity, high volume data streams in real time. In their design, the authors achieved up to 25 times better streaming throughput, and they hinted at new research that may allow another leap in throughput speeds.

For the seventh and last article in this issue, "Can Agile, Systems Engineering, and Independent T&E Coexist and Cooperate?," Dave Brown, Ph.D., and Dave Bell, Ph.D., state that systems engineering provides the top-level structure and process to integrate the Agile process into large scale developments. They explain that Agile teams generally use the DevSecOps continuous process, generally with significant automation, for delivery of incrementally improved software. The answer to the question in the title is "yes" with the conclusion that the combination of Agile, systems engineering, and independent T&E shows great promise to enhance the development of complex systems.

I hope you enjoy this second issue of 2019 for *The ITEA Journal of Test and Evaluation*. By the time you receive issue 40-2 in June, the September 2019 issue 40-3 is being finalized. That theme in September will be **"Aligning Modernization of DoD Test Ranges with National Defense Strategy."** For the next issue (the last issue of 2019), 40-4, the deadline for submissions is just after September 1, 2019, and the theme will be **"Drowning in Data: How to Gain Timely Information and Knowledge from Data."** We have posted all themes and descriptions for 2020 and 2021 on the ITEA website. We will post more themes later in 2019. Please provide feedback on the choice of themes, and please write early and often. ❑

The ITEA Journal of Test and Evaluation 2019; 40: 74-75

Sometimes a Picture *Is* Worth a Thousand Words

Steve Hutchison, Ph.D.
US Department of Homeland Security, Washington, DC

In the fall of 2005, I was a newly minted senior executive service member in the Defense Information Systems Agency (DISA), enjoying an evening dinner out with my beautiful wife, when she spotted an old World War II poster amidst the multitude of wall-hangings adorning the walls of the restaurant. My wife pointed and said to me, “Isn’t that what you do?” Curious, I turned to look and saw the poster depicting a soldier throwing a grenade, thinking to himself “God help me if this is a dud!”, and a caution to anyone supporting the war effort that “HIS LIFE IS IN YOUR HANDS.”

Steve Hutchison, Ph.D.

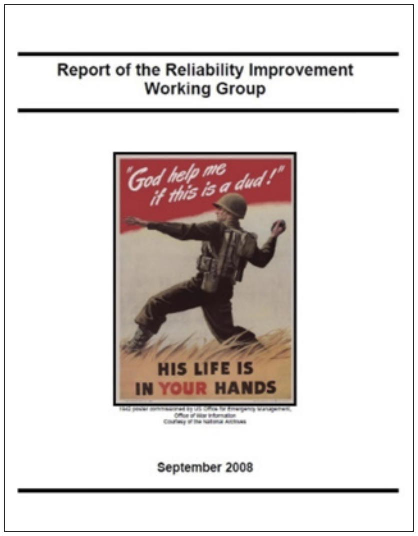
Although it was possible that she was referring to my past life as an US Army Infantryman, a time when I may have thrown a grenade once or twice—albeit in training—it was clear to me that my wife saw in that image a simple visual representation of the things I do as a Test and Evaluation (T&E) professional. We make sure things work, because Warfighter’s lives may depend on it.

I found it to be a powerful image with an equally powerful message. The things we do behind the scenes to enhance the capabilities of the those serving in harm’s way, whether they be Warfighters, Law Enforcement Officers, First Responders or others, are incredibly important—and we better get it right. As a T&E Professional, I take this very seriously. That picture spoke to me.

Intent on obtaining my own poster, the search began. Fortunately, in the age of the internet and Google, the poster was easy to find, and the first copy immediately went up on the wall in my office. It hangs there to this day.

Now, this also occurred at the same time I was launching a professional development seminar series for the DISA T&E workforce called the “T&E Forum.” My intent was to invite leaders in the T&E community to come and talk to our folks, so that they could hear from others about the things that are important in our business. I also had a bit of an ulterior motive: having had previous experience in Army T&E and in the office of the Director, Operational Test and Evaluation (DOT&E), I knew the DISA T&E community was a largely unknown entity, and suffered (cynics might have said “benefitted’) from being “out of sight; out of mind.” I knew that by inviting these folks, especially the Department of Defense (DoD) leaders, I would begin a process of putting DISA on the T&E map.

I invited the Honorable Dr. Charles McQueary, DoD DOT&E, to inaugurate the DISA T&E forum. And, Dr. McQueary delivered. Our folks were engaged and



inspired, and at the end, when Dr. McQueary flipped to his last slide, the one featuring the official seal of the DOT&E, Dr. McQueary made the remarkable comment to our roomful of information technology testers, that the streamer on that seal, the one that says "KEY TO WEAPONS THAT WORK", should perhaps say "key to systems that work," or something along those lines.

To thank the Honorable Dr. McQueary for his time and presentation, I presented to him a small framed version of that WWII poster, with the hopes that it would speak to him as much as it did to me.

I then did the exact same thing for my next two T&E Forum speakers: the Director of the Developmental Test and Evaluation Office, Chris DiPetto, and the Director of the Test Resource Management Center, John Foulkes, Ph.D. The senior leaders in the Office of the Secretary of Defense (OSD) made quite the impression in DISA—and as a result, I think the DISA T&E organization was beginning to understand that it was part of something much bigger than just our own combat support agency.

That image must have resonated with my speakers as well, especially as a way to communicate the critical importance of system *reliability*. When the DoD Reliability Improvement Working Group published its final report, for example, the poster was featured on the report cover. And, when the efforts of the reliability workgroup were described in *The ITEA Journal*, the Journal editors decided to use the poster on its cover as well. In the many times that I visited the DOT&E since then, I have quietly allowed myself a moment to be proud that the poster still hangs outside the Director's door.

In the fall of 2009, I experienced my own visceral reminder of the importance of what we do in T&E. My wife and I traveled to Joint Base Lewis-McChord in Washington State to see our son off to the war in Iraq. As we sat in his hotel room the evening prior to his departure, he carefully adjusted the fit of his just issued body armor. I could not escape the feeling that if my son needs it, this stuff better work.

"This stuff better work" shapes my role in overseeing T&E for the Department of Homeland Security. I know that if you want to know if a system works, you have to test it; but if you want to know with confidence, you have to plan, resource, and conduct T&E accordingly. I do not let Program Managers or testers or users cut corners—what a disservice it would be to allow our operators to think something works when we haven't tested it thoroughly. I also use the poster in presentations in the classroom; every time I speak at the advanced Program Management or T&E classes at the Homeland Security Acquisition Institute, I use the image to convey to the students something else I heard from Dr. McQueary: "It is far more important for a system to be effective *when it is needed* than when it is available" (italics added). The poster always leads to a lively discussion of reliability vs. availability.

Most recently, in December 2018, more than a decade after I presented that image to the DOT&E, the current DOT&E, Honorable Robert Behler, included the poster in his presentation at the 35th annual ITEA Symposium.

Sometime images can be powerful. Whatever it is that reminds you of the critical importance of what we do, embrace it. It makes a difference. ❑

STEVE HUTCHISON, Ph.D., is the Director for Test and Evaluation in the Department of Homeland Security, and previously served in a number of test and evaluation leadership positions in the Department of Defense. Dr. Hutchison is a US Army veteran.

The ITEA Journal of Test and Evaluation 2019; 40: 76-82

Cyber Testing in a Rapid DoD Acquisition Environment

Kevin McGowan
COLSA Corporation, Supporting 47th Cybersecurity Test Squadron
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The need to deliver functional capability to the warfighter at the speed of need is driving an increasing number of acquisition programs towards the use of Agile and rapid prototyping acquisition strategies. But, hand in hand with the need for rapid capability delivery is the need for these systems to be cyber survivable in an increasingly complex cyber contested battlespace. This paper addresses some challenges that Agile and rapid programs present to the cyber test community, as well as some strategies that may be employed to help ensure the delivery of cyber survivable systems to the warfighter.

The increasing interest in rapid prototyping, Agile software development (ASD) and Agile deployment strategies amongst senior leaders, program managers, and warfighters has placed renewed pressures upon the acquisition community to deliver software capabilities to the warfighter faster. An urgent need or rapid delivery schedule, however, does not alleviate the system from the requirements to be both survivable and able to perform its mission functions in a threat environment. This includes ensuring that the system is both cyber secure and cyber resilient. The system must have appropriate protections in place and be capable of successfully and effectively executing its mission functions during and following a cyber-attack.


Kevin McGowan

Need for Cyber Testing

10 United States Code directs the Department of Defense (DoD) to ensure the "availability, integrity, authentication, confidentiality, nonrepudiation, and rapid restitution of information and information systems that are essential elements of the Defense Information Infrastructure." This includes conducting "vulnerability and threat assessment[s] of elements of the defense and supporting nondefense information infrastructures that are essential to the operations of the Department and the Armed Forces."

Title 10 further directs end-to-end testing of system capabilities and all interrelated systems (i.e., system-of-systems) needed to employ and support included capabilities. Title 10 also states that Operational Test and Evaluation must be conducted using typical users or units who will operate and maintain the system or item under conditions simulating combat stress and peacetime conditions. These combat stresses include both kinetic and cyber threats. Department of Defense Instruction (DoDI) 5000.02 further directs the lead Operational Test Agency, in consultation with the user and the Program Manager, to identify realistic operational scenarios based on the system's Concept of Operations and mission threads derived from the Joint Mission Essential Task List or DoD Component-specific Mission Essential Task List. The system's operational test must include an evaluation of its operational effectiveness, suitability, and survivability while conducting the aforementioned operational scenarios and mission threads in a realistic cyber threat environment (to the maximum extent possible). Bottom line, the system must be capable of effectively performing its mission functions during and following a cyber-attack.

While National Defense Authorization Act Section 804 programs are not required to comply with all Joint Capabilities Integration and Development Systems (JCIDS) and DoDI 5000 series requirements normally imposed upon other programs, rapid and Agile acquisition systems must still be demonstrated and tested in operationally relevant environments. This includes evaluating the system's cyber survivability (i.e., cybersecurity and cyber resiliency) in an operationally representative cyber threat environment. This requirement creates interesting challenges to the acquisition community as the stakeholders work toward delivering rapid capabilities to the warfighter that are not only on cost and schedule, but are also cyber survivable.

In the case of Section 804 programs that rely heavily upon existing technologies, the system may not have been designed with a robust set of cybersecurity and cyber resiliency requirements. The lack of a strong cybersecurity foundation does not alleviate the need for the system to be cyber survivable in a cyber threat environment, however. The requirement to begin production within six months of contract award and for the system to be fielded within five years further reduces opportunities for significant system modifications that may be needed in order to design-out potential cyber vulnerabilities. The time constraints, in turn, require many systems to "bolt on" cyber protections and mitigations, or to accept the risk of cyber vulnerability exploitation. Regardless of the path taken, cybersecurity and cyber resiliency testing are still necessary in order to identify cyber vulnerabilities and to evaluate the effectiveness of system security controls and vulnerability mitigations put in place. Testing further assesses the system's inherent cyber resiliency to include the overall system-of-systems resiliency as new vulnerabilities are introduced into the larger operational system-of-systems environment. The results of these cooperative and adversarial cyber tests paired with parallel and/or previous assessment results help ensure risk, system modification, deployment, and employment decisions are appropriately informed.

As an alternative to being forced to accept the risk of cyber vulnerability exploitation, consideration should be given to acquiring prototypes and existing technologies that have already incorporated cyber survivability into the original system design. Incorporating a cyber resiliency assessment/demonstration into the prototype's functionality demonstration can help assess the effectiveness of the prototype's inherent cybersecurity and cyber resiliency and inform the acquisition decision. A paradigm shift within the DoD acquisition community to provide special considerations to programs that have already incorporated cybersecurity protections and demonstrated cyber resiliency qualities (i.e., a capability to continue performing its mission during and after disruptive cyber-attacks) can help drive significant survivability and system effectiveness improvements for Section 804 programs and other DoD acquisitions. The acquisition of already cyber resilient systems will also help reduce program cost, schedule length, and the need for expensive system upgrades which "bolt on" system protections post deployment.

Cyber Test Challenges

Continuous development, evolving requirements, and rapid and continuous deployment of incremental capabilities are just three key principles shared by Agile programs seeking to take full advantage of the Agile development and deployment strategies. While these core principles provide strength to programs, they also present challenges to the test communities.

In the traditional waterfall development model, program schedules are constructed with dedicated time blocks for developmental, integrated, operational, and cyber testing. The system's design and requirements are generally locked down during the contract award and design approval processes with minimal opportunities for significant requirement changes once formal development begins. This makes it easy for the functional and cyber test agencies to develop test plans early with a high level of confidence in what will be delivered. Developmental cyber tests are conducted on individual sub-components and code segments in a laboratory or developmental test environment as the system components become available. The developmental cyber test scope is then systematically expanded to include full hardware/software components and connected systems culminating in a comprehensive evaluation of the final system before it proceeds to operational test and full system deployment. Capitalizing on touchpoints throughout the development process, system changes should be made throughout the development and developmental test cycles as deficiencies and vulnerabilities are discovered. In this building block approach, it is generally accepted that test results may drive system changes and potentially delay programs while functionality and cyber survivability deficiencies are corrected. Agile programs, however, with dynamic requirements, regular functionality deliveries, an emphasis on rapid capability delivery, and little tolerance for extended test periods, require more dynamic test strategies.

Functional testing in an ASD environment can typically be scoped after performing an assessment of the system backlog which documents requirements implemented to date. Cybersecurity and cyber resiliency testing, on the other hand, requires continuous end-to-end and system-of-system assessments to determine the effectiveness of implemented cyber protections and system resiliency capabilities. A simple code adjustment may have cascading unintended effects throughout the system and can render previously effective security protections ineffective. Continuous cybersecurity and cyber resiliency testing helps ensure code and/or hardware changes haven't created new vulnerabilities. Continuous testing can also help ensure new exploitation techniques and tools used to exploit vulnerabilities on other systems are ineffective on the system being developed. It can also help determine whether previously identified vulnerabilities have been adequately addressed in the system update. Unlike waterfall programs, however, the rapid delivery strategy means time, and in some cases testers, may not be available for dedicated hands-on, end-to-end testing without imposing undesired deployment delays.

Despite these challenges, Agile programs provide a unique, and arguably, one of the best opportunities to continuously implement system design improvements. As these programs remain in a near-perpetual state of development, the fixes for identified vulnerabilities can be rolled into the Backlog (preferably at the top of the list) for incorporation. In so doing, programs can help ensure vulnerability remediation is expeditiously incorporated into the system without a need for generating and implementing a Plan of Action and Milestones (POA&M). However, in order to take full advantage of the opportunities presented by Agile program constructs, acquisition, development, test, and deployment strategies must be tailored appropriately from program onset. Posturing the program for Agile development, continuous system improvements, and integrated incremental test activities are critical to taking advantage of the benefits of Agile development and deployment strategies. Contract types and structures must support Agile system development, to include collaborative government engineering and tester involvement, in all stages of system development in order to reduce cyber vulnerabilities. Program stakeholders must be able to adjust requirements and system design, as required, to ensure that a secure system is developed and potential vulnerabilities are remediated (or mitigated) throughout the development process.

Development and Test Environments

Historically, many programs have experienced functional and cyber survivability challenges when transferring from contractor development environment(s) to test environments, and then again when migrating to the operational or production environment. The utilization of operationally representative development and test environments can help minimize disparities in system performance between these environments by ensuring the software is developed to work in the environment it is planned to operate within vs. one with different interfacing hardware and/or software components. The development and test environments should utilize the same hardware and software configurations (but not necessarily the same scale) as what will be found in the operational environment. In cases where the system under test will interface with external systems once deployed, the operational interfaces and data flows should be emulated in the test environment (and development environment where feasible). In the absence of representative hardware, it may become necessary to incorporate virtualized components, at least until the actual hardware system becomes available. The virtualization should include the use of all data protocols/formats that are possible through the system interfaces, not just the protocols/formats that are desired or expected.

Finally, the differences between the development, test, and operational/production environments should be articulated prior to development approval with potential performance, security, and test limitations/challenges being clearly identified to inform risk and acquisition decisions. For example, test limitations may drive the need for additional cyber test assets and/or separate cyber test environments/instances. By aligning the development, test, and operational/production environments, the program can better support integrated test opportunities and provide a high level of confidence that the developed capabilities will work in the operational environment. This alignment will also assist in reducing program costs, reducing program schedules, and minimizing the chances of introducing new cyber vulnerabilities (leading to reduced system effectiveness, additional system changes, and program delays) when moving from one environment to another.

System Security Engineering

Once the development environment, test environment, and Agile posture are established, it is important to ensure cyber survivability is built into the original design. This is best accomplished through comprehensive system security engineering (SSE) and secure software development processes such as Secure Development Operations (SecDevOps), which integrates security considerations into the underlying collaborative, rapid delivery focused, and highly automated DevOps culture. The SSE and secure software development processes strive to design-in security controls and design-out identified and/or potential cyber vulnerabilities throughout the development process. This includes integrating security into the core code, coding tools, underlying infrastructure, and overall culture. Software and hardware pedigree should also be closely monitored. The monitoring should ensure that system code and architectural information do not get into the hands of non-trusted actors; system components, sub-components, and code are not obtained from non-trusted sources; and code obtained from outside sources is not used without first accomplishing a thorough functionality and security review. By developing the system from the ground up with security in mind, many common cyber vulnerabilities can be designed out of the system and/or avoided entirely. By eliminating cyber vulnerabilities early, costly and less effective "bolt-on" fixes can be avoided later in the development process (or worse, post deployment).

The integration of all key stakeholders into an integrated System Security Working Group (SSWG) (or equivalent) that is Agile trained and vested is also instrumental to the successful implementation of SSE. Posed to support rapid ASD, the SSWG should serve as a focal point for continuously gathering and analyzing system information, mission and requirement adjustments, performing vulnerability and threat assessments, integrating system security considerations into the requirement set, and ensuring the development of appropriate protection and security plans. These iterative activities must be accomplished at a speed commensurate with the system's development and release cadence. Any identified adjustments should be inserted into the backlog as soon as possible in order to ensure timely system adjustments are made.

To be truly effective, the SSWG should be stood up at program start, remain active throughout the acquisition life cycle, and be comprised of representatives from:

- Program Management
- Systems security engineering
- Systems engineering
- Lead Developmental Test Organization (LDTO)
- Operational Test Agency (OTA)/Operational Test Organization (OTO)
- Participating cyber test organizations (also known as cyber test agencies)
- System Developer(s) (post contract award)
- Logistics
- Authorizing Official's office
- Trusted Systems and Networks
- Intelligence/counterintelligence agency(ies)
- Program protection office
- Defense Security Service (DSS)
- Anti-Tamper Executive Agent (ATEA)
- Information Protection (IP) office

The actual SSWG composition will be largely dependent upon the size and nature of the program, but the underlying purpose to identify potential cyber vulnerabilities early and seek to design out (or mitigate) those vulnerabilities, will remain unchanged. It is important to integrate cyber survivability into the foundational system design as earlier as possible so that potential vulnerabilities are eliminated throughout the acquisition life cycle.

Additionally, like traditional acquisition programs, iterative Mission-Based Cyber Risk Assessments (MBCRA), incorporating in depth technical, intelligence/threat, mission, safety, criticality, and vulnerability analyses, should begin at program onset and continue throughout the entire acquisition process. Utilizing all available system, mission, and threat information, the MBCRA provides a means for identifying potential cyber vulnerabilities early and continuously, and helps identify areas where additional attention is warranted. Performing the initial MBCRA event before locking down [initial] system requirements enables the development of comprehensive cybersecurity (e.g., cyber protections) and cyber resiliency (e.g., cyber survivability attributes) requirements prior to Request for Proposal (RFP) release. This effort may also aid significantly in identifying appropriate security controls and identifying cyber risks. Converting the system security controls into engineering requirements that should be incorporated throughout the ASD process can also help ensure cyber survivability is built into the system instead of "bolting on" more costly and less effective protections later in the development cycle. Continuous MBCRA updates conducted prior to major decisions and cyber test activities, taking into consideration technical/architectural, operational/mission, and intelligence information updates, also help ensure current cyber risk information is taken into consideration during design and program decisions throughout the program. Updated MBCRAs should also be used to help scope and focus cyber test activities, identify and update cyber test resources, schedule cyber test assets, and ensure the limited cyber test resources are focused on performing comprehensive testing of high risk areas.

Cyber Test Strategy

Software Development and Automated Testing

One of the most significant test challenges experienced by rapid and Agile programs is the development and execution of a cyber test strategy that evaluates the system's cyber survivability (i.e., cybersecurity and cyber resiliency) without negatively impacting the delivery schedule. Test-based development, automated test executed during development, operationally representative development and test environments, and a fixed release cadence/schedule can help ensure an effective integration of cybersecurity and cyber resiliency testing throughout the Agile development and deployment process.

In test-based development, also known as test-driven development, the software developers generate automated tests that evaluate the system's capability to meet a specific requirement. After the automated tests are written, the developers produce the minimum amount of code necessary to pass the test, running the new code through the automated test sequence frequently to assess progress. Once the test passes, the code is tailored (as required) to meet applicable standards. The tailored code is then rerun through the automated test sequence, to include the accomplishment of automated regression testing. This ensures the new code still meets the requirements and does not break a previously functional system. Once complete, the automated test sequence is added to the larger automated test bank for future regression testing.

Automated testing is a key component of successful ASD but it does not replace the need for hands-on user testing, penetration testing, or operational testing. Automated testing is well suited for positive functional testing that verifies the system functions perform as required. It can also be used to help stress the system and perform basic negative testing such as the insertion of incorrect data types into data fields to evaluate whether the system will appropriately and gracefully handle invalid inputs and user actions. Automated cyber testing may also be effective in ensuring security controls are in place and can help validate the systems cybersecurity posture (the first half of cyber survivability testing), especially when executed in conjunction with automated functional testing throughout the ASD pipeline.

Hands-on Testing

Regardless of the advantages and need for automated testing, hands-on functional, user acceptance, and cyber resiliency testing are still required. The challenge is building the hands-on testing activities into the Agile deployment schedule without imposing significant functional delivery delays or excessively straining limited test resources. The "easy" answer is a layered and incremental test strategy. Building upon the automated functional, regression, and cyber testing already accomplished during the ASD process (in the operationally representative development environment), limited hands-on government acceptance testing, focused on the newly delivered functionality, should be conducted by the LDTO. As this team should be integrated into the ASD process itself, this step could be quick or even validated by actions already performed prior to code submission for government acceptance.

Once the government accepts the functional delivery from the developer, operational users (not those directly involved in system development) should evaluate the delivered functionality in the operationally representative test environment to ensure it will meet mission needs (ideally in conjunction with integrated/operational test efforts). The operational user evaluation should include some regression testing to ensure the new release does not negatively impact previously delivered functionality. In parallel with the user acceptance testing, hands-on cyber penetration testing should be accomplished in a separate but operationally representative cyber test environment. In so doing, the cyber testing does not negatively impact user acceptance testing or the other functional development timelines. This testing should not only focus on validating the effectiveness of the implemented cybersecurity protections and controls (i.e., cybersecurity testing), but also on attempting to cause operational effects by exploiting newly identified and already known cyber vulnerabilities (i.e., cyber resiliency testing). The cyber resiliency testing, in conjunction with the automated and hands-on cybersecurity testing, will determine the system's overall cyber survivability (in a test environment). The greater the likeness between the test environment and the operational/production environment, the greater the confidence level that the system under test will behave similarly once deployed. While not ideal, operational needs may drive deployment of the system's new functionality prior to the completion of the cyber survivability assessment. Regardless of the situation, cyber testing should continue as planned with all negative findings being identified promptly for risk identification and corrective action.

After the system is deployed to the operational environment, it will need to undergo operational test(s). This includes functional and cyber survivability testing that emulates operationally representative environments and cyber threats. The timing of the tests should be dependent upon the scope of the functionality released since the previous end-to-end operational test. For example, weekly releases of minor functionality improvements may not merit full end-to-end testing each week but consideration should be given to performing periodic comprehensive testing in the operational environment based upon an established test cadence, or when it is determined that sufficient changes have been released since the last comprehensive test period to warrant dedicated test. Likewise, programs that consolidate the capabilities generated by multiple sprints into a single minimum viable product (MVP), or formal release that is deployed on a slower cadence (e.g., quarterly or bi-annually), should give serious consideration to aligning comprehensive developmental and operational testing with these releases. This may include the accomplishment of cooperative cyber vulnerability identification (CVI) and/or adversarial cyber developmental test (ACD) activities in the developmental or test environments prior to formal release.

The Cooperative Vulnerability and Penetration Assessment (CVPA) should be accomplished as early in operational test as possible with the Adversarial Assessment (AA) occurring after sufficient time has been allotted for the program office to correct vulnerabilities discovered during the CVPA. The AA should also be conducted after the users have become comfortable with expected system behaviors during normal operations. In some cases, a minimal delay between CVPA and AA may be warranted in order to more expeditiously identify vulnerabilities present in deployed systems, and to assess the potential mission impact(s) if identified vulnerabilities are exploited. Ideally, the AA will be accomplished on the live system while operational users perform operational missions (or operationally representative test missions) in order to ascertain overall system resiliency. The system's resiliency assessment should include not only the operational effects of vulnerability exploitation but also user identification of cyber-attacks and subsequent mitigation efforts. Due to risk considerations, it may be necessary to perform effects-driven AA testing on a dedicated cyber test asset or software instance.

Vulnerability Identification and Remediation

In the interest of time, abbreviated or "quick-look" test reports should be generated following each cyber test period. The abbreviated test reports should quickly summarize findings, describe observed and/or derived operational impacts, and provide recommendations (if able). In the event a more detailed report is warranted, the "quick-look" report will need to be followed by a more comprehensive report at a later date thereby minimizing the delay between test results and deficiency/vulnerability remediation.

If at any point functionality problems or cyber vulnerabilities are identified before deployment, a risk decision must be made by the program leadership and user community as to whether the new code should be deployed or delayed until the deficiencies and/or vulnerabilities are corrected. In cases where functional deficiencies or cyber vulnerabilities are discovered after the new code is deployed, consideration should be given to rolling back the previously deployed release until the deficiencies and/or cyber vulnerabilities are remediated. In both cases, the corrections should be placed at the top of the Backlog for immediate implementation and release.

Exploitation Discovery

The fast paced development and deployment aspects of Agile and rapid prototyping programs dictate a certain level of risk acceptance. Too often, comprehensive cyber survivability testing is not accomplished prior to system deployment. And, even if hands-on penetration and exploitation testing was accomplished, new vulnerabilities and exploitation techniques are continuously developed and refined. As such, it is possible that evidence of an actual vulnerability exploitation may be found during the course of system development, developmental cyber testing, operational cyber testing, or real world operations. In these cases, evidence must be preserved, and appropriate authorities must be notified immediately. This may include the notification of military and/or civil law enforcement agencies. The exploited vulnerability should also be remediated as soon as possible. In some cases, mitigation measures may need to be implemented until the vulnerability is eliminated.

Rapid Delivery of Cyber Survivable Systems

When fully embraced, ASD and rapid prototyping can be very effective acquisition strategies, but care must be taken to posture the program's acquisition, development, deployment, and test strategies to fully assess and incorporate cyber survivability. This should include, but is not limited to, the incorporation of sound SSE processes; security driven development culture and practices; the utilization of operationally representative development and test environments; incremental and iterative cybersecurity and cyber resiliency testing; and continuous two-way communication and cooperation between developers, testers, and customers. The contract and stakeholders must also fully support rapid remediation of identified vulnerabilities throughout the acquisition life cycle and fully accept the fact that functionality deliveries may need to be delayed or rolled back in order to ensure a cyber-survivable system is delivered to the warfighter. ❑

KEVIN McGOWAN currently works for COLSA Corporation supporting the 47th Cybersecurity Test Squadron and has more than 20 years of Air Force computer programming, strategic airlift, and test experience. As a Cybersecurity Test Engineer, he guides the design of cybersecurity and cyber resilience test and evaluation of DoD systems. He advises acquisition programs, developmental test teams, and operational test teams on test policy, integrated test, test strategy development, test related document generation, requirements generation, and cyber vulnerability identification activities. He also assists with the drafting of Air Force and DoD Test and Evaluation processes, policy, and guidance. Kevin has a M.S. in Military Operational Art and Sciences from Air University and a M.S. in Aeronautical Science Technology/Aviation Management: Aviation Safety from Embry-Riddle Aeronautical University and a B.S. in Computer Science from the United States Air Force Academy. He is a certified CompTIA Advanced Security Practitioner and has a Level-3 DAWIA Acquisition Test and Evaluation certification.

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Going Faster: Implications for Test and Evaluation

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Agile software. DevOps. Section 804. Rapid prototyping. Faster, smarter acquisition. Innovation. Regardless of the label or development philosophy, the Department of Defense (DoD) acquisition programs are trending towards more rapid fielding and taking more risk. What does this trend mean for the test and evaluation community? Does taking more risk mean cutting corners and less testing or just testing more quickly? How can testers go faster while still mitigating the hazards often involved in developing new systems?

The US Air Force test enterprise has embraced this recent DoD emphasis on delivering innovative and affordable capabilities to our warfighters at the speed of relevance.[i] Given the rapid acceleration of technology and evolving threats, we can no longer take decades to develop weapons systems that need updating before they are even fielded.

The good news is that DoD test personnel have always been creative and innovative out of necessity as they develop new techniques and enhance our world-class test ranges and facilities to deliver decision-quality data about the performance and effectiveness of boundary-pushing systems. The motto of the Air Force Test Center is "Ad Inexplorata," which translates as "Toward the Unexplored."

In the mid-1990s, when I was the commander of the 846th Test Squadron at Holloman Air Force Base, New Mexico, my test team required about two hours to lay out a mile-long plastic bag that was later filled with helium for high-speed sled runs. The idea of shooting a missile mounted on a sled through a bag of helium to reduce drag and achieve speeds around Mach 6 was certainly an innovative idea. But laying the bag wasn't always such an easy task; a decade before I arrived, the job was a labor-intensive process that took a half-dozen people at least a week. At times, the installation had to start anew when desert winds blew the bag away. The helium bag team knew there had to be a better way. Over the next five years or so, the team came up with dozens of small and large innovations: they improved training and installation techniques, worked with a manufacturer to develop a stickier tape, and built their own machine to automate the laying and taping process. Some of the innovations saved minutes or hours and others saved days. The final result: the two-hour installation time that no longer drives the test schedule, freeing up the world's longest and most precise test track for additional testing, maintenance, and improvements.

Going Faster: Key Principles

The main goals of test and evaluation (T&E) are to reduce risk and provide data to inform acquisition decisions or answer warfighter capability questions. Rapid acquisition relies on a cycle of rapid learning, and T&E is the primary means of learning. As Wernher Von Braun, Ph.D. once said, "One good test is worth one thousand expert opinions." Thus, T&E still matters and is even more important during rapid acquisition of systems with high technical risk so we don't pass that risk along to the warfighter. Delivering performance at the speed of relevance still requires independent testing to ensure unbiased results, and we must ensure that testing is also done at the speed of relevance.

Achieving efficient T&E during rapid acquisition requires understanding of the intended concept of operations—how the user expects to employ the system, along with early tester involvement, deliberate planning of tests to inform acquisition and warfighter decisions, and disciplined test execution followed by relevant and timely reporting. Smaller, more frequent tests conducted by an integrated developmental and operational test team using the system in a mission focused, operationally relevant environment will enable early discovery of problems that can be fixed prior to fielding. Early tester involvement will also reveal system deficiencies earlier when they are more affordable to fix. This often results in the warfighter receiving new or improved capabilities earlier than they would if programs identify deficiencies late in development.

However, rapid does not mean reckless, nor does it mean ignoring the "ilities" that make a system suitable as well as operationally effective. Rapid acquisition may necessitate taking greater technical or program risk, but not at the expense of a test program that ensures the safety of test personnel and the system under test. Requirements related to aspects such as interoperability, maintainability, and security are also still relevant and require testing.

The key to achieving rapid testing is early and continuous tester involvement during a program. T&E personnel provide advice to program managers regarding overall test strategies, schedules, and resources required. These elements form the basis for flexible test planning and streamlined approval processes. In addition, by virtue of their training and experience, T&E personnel are world-class experts in risk management; involving them early ensures safe test conduct and scoping the test program to examine high-risk technical areas that impact operational effectiveness and suitability versus a focus on compliance with specifications.

Likewise, during testing, "quicklook" reports and daily communication cycles become more important. In particular, continuous feedback cycles and more-frequent adjustment of detailed test plans may be required to stay on schedule and accommodate rapid update cycles driven by approaches such as rapid prototyping, agile software development, or DevOps processes.

Air Force T&E Practices That Enhance Rapid Acquisition

Policies established by the Director, US Air Force Test and Evaluation (AF/TE) emphasize decision making at the lowest possible organizational layer. This streamlines decision making and ensures all decisions related to test execution, including test safety and technical adequacy, are made by our highly-qualified T&E workforce.

Air Force policies also encourage early tester involvement. Air Force Instruction 99-103, *Capabilities-Based Test and Evaluation*, requires program managers to establish an Integrated Test Team (ITT) prior to Milestone A for new programs or immediately after the Material Development Decision for programs starting after Milestone A. ITTs are collaborative organizations that bring together empowered members from a program office, developmental test, operational test, and other functional organizations with test equity to develop the test and evaluation strategy using an integrated and harmonized approach.

Early tester involvement permits test-driven design and design for test. Test-driven design, a best practice adopted from software development that is equally applicable to hardware, ensures that systems can actually be tested. For example, including sensors or key telemetry parameters early in the design process results in more efficient test execution and faster evaluation compared to adding test-unique hardware and software at a later date.

The developmental test community is also adopting a streamlined safety review process while retaining the rigor required to minimize the risk involved in testing new systems. Program managers are encouraged to introduce this test-driven Systems-Theoretic Process Analysis into program test strategies as early as possible to maximize schedule savings and provide more insight into safety risks.

With ITTs, test is test. The distinction between developmental testing (DT) and operational testing (OT) is merely whether the test results are used to mature the system design (DT) or to inform the warfighter (OT). Early tester involvement in ITTs also encourages the test design to incorporate mission-focused elements that enable earlier operational assessments. This, in turn, provides earlier OT feedback creating opportunities to identify potential operational deficiencies prior to formal Initial Operational Test and Evaluation. Mission-focused test and an integrated DT/OT strategy also may provide opportunities for some operational data to be collected during DT events.

Finally, the Air Force T&E enterprise encourages innovation in our test units. As an example, in July 2016, the 412th Test Wing at Edwards Air Force Base created the Emerging Technology Combined Test Force (CTF) to develop test techniques and methods for advanced autonomous systems, artificial intelligence, machine learning, and counter-unmanned aerial systems. In addition to developing new test methodologies, the Emerging Technology CTF has proved a safe and effective means of realizing integrated, Agile DevOps in flight test. A recent program safely and effectively achieved a more than 25-fold increase in sortie generation using an Agile DevOps approach.

This article has only touched on the Air Force's recent changes that will ensure our ability to test at the speed of relevance. More details can be found in the recently released update to our "Air Force Test and Evaluation Guide," available at https://www.dau.mil/tools/t/AF-TE-Guide.

Innovation and change are deeply embedded in the DNA of the Air Force T&E enterprise. We are never satisfied with the status quo, primarily because the systems and techniques we use to test new systems have to stay a step ahead of the systems themselves. We not only identify with the recent DoD emphasis on going faster, but embrace the challenge and look forward to continuing as a valued partner in helping deliver warfighting capabilities both now and in the future. ❑

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Endnote

[i] Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge.

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Let's Meet in Kauai One More Time

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Steven Gordon, Ph.D.

The 36th International Test and Evaluation Association (ITEA) Education Symposium is planned for 12-15 November 2019 at the Kaua'i Marriott at 3610 Rice Street, Lihue, Hawaii 96766. The hotel is near the Lihue Airport, and the hotel's phone number is 808-245-5050. This will be the third ITEA Symposium held in Kauai. It is also the third ITEA Symposium planned by Stu Burley, who passed away in Kauai, August 18, 2018. Anytime he was needed, he was there. So, of course, Stu provided outstanding support to ITEA in 2013 when he helped plan and organize the outstanding Acoustics Unmanned Autonomous Workshop in Kauai. Every time I attended a conference in Hawaii, Stu was there. I still look for him. Stu worked with all the government entities in Hawaii, and he worked for much of his life at the vitally important Pacific Missile Range Facility (PMRF) on Kauai. Stu will be honored again at this upcoming Symposium.

We are planning a very robust event in November with tutorials, plenary sessions, technical sessions, poster papers, and 45 exhibit booths. Our first two events in Kauai each had registration levels greater than 600 attendees. The exhibit halls were fully

Aerial view of part of the PMRF
(https://upload.wikimedia.org/wikipedia/commons/c/cf/PMRF_aerial.jpg)

booked, the plenary speakers spoke to many international issues, the numerous technical sessions were well attended, and the poster papers lined the walkways outside the ballrooms. The theme of this 2019 event is Challenges for Future Threats, and the goal is education and sharing of ideas for the future of test and evaluation (T&E). Please review the 2019 Symposium information at: *https://www.itea.org/event/36th-international-test-and-evaluation-symposium/*.

Hawaii is a unique location for the ITEA Symposium because Hawaii hosts 11 military bases and components of all the military Services. One of those bases is the PMRF, the largest instrumented multi-environment training and test range in the world, hosting many Coalition test events. Many of the plenary speakers may have valuable ideas of how acquisition and T&E can be accelerated and improved to better support the warfighters in their command.

Organizers of this event recognize that global and regional threats are developing larger, more capable military forces. These potential adversaries are armed with increasingly sophisticated weapon systems incorporating new technologies, and they are developing new tactics. The more advanced threat systems are being continually improved in range, speed, stealth, precision, and lethality. How do we meet these challenges? Not by slowing down. Acquisition and T&E of new weapon systems and defensive systems for the United States and Coalition Partners must be ready to rapidly provide decision makers with the data required to make critical decisions on continued improvement or fielding or both. This Symposium will include discussion and education on how we (the Coalition) will meet these challenges, improving at each step.

Pending final program decisions, here's the planned sequencing of the Symposium events. The tutorials will be scheduled in two 4-hour blocks on Tuesday, November 12, 2019. Plenary speakers, technical paper presentations, poster papers, and exhibits will be available for at least the next 2 days (Wednesday and Thursday). Tours may be available on Friday.

Proposals for educational tutorials and for technical paper presentations must be provided as a short (500 words or less) abstract no later than June 16, 2019 to *Symposium@itea.org*. Check the website or email notifications for any changes to this due date. The abstract must be non-marketing and should succinctly describe the contents of the presentation. All presenters are responsible for having their final submissions cleared by the authorizing agent for public release. Once abstracts are accepted, authors will be notified by August 9, 2019 and will be given the contact information for their Session Chair. Authors can choose to write a paper or just make a presentation. The lonely Editor of *The ITEA Journal of Test and Evaluation* hopes you will decide to write a paper describing your tutorial, plenary talk, technical presentation, or poster topic; and submit a paper meeting these requirements: *https://www.itea.org/submissions/*. Abstracts accepted for presentation, along with the slides, will be available online for attendees after the Symposium concludes.

Tutorials are typically scheduled for either a half-day or full day, should include comprehensive presentations on well-established topics, and may include hands-on exercises using various software and/or hardware tools. Technical track session presentations are shorter than tutorials and usually last 30 minutes. While tutorials go into considerable depth, technical track session presentations give quick holistic overviews of interesting emerging topics with a concentration on fundamentals and predictions about the future of these topics. Poster presentations, usually displayed in or near the Exhibit Hall, are designed to present work-in-progress, new ideas, and emerging fields and research topics in T&E. Poster presenters are expected to bring their printed poster and handouts, and to be present during scheduled times for the poster presentation session(s). Attendees will browse the posters and directly interact with the poster presenters. Thus, the poster session is intended to be an informal, conversational forum for new ideas. Some poster presentations may also be designated as back-up presentations for technical sessions.

Here is a list of the topics encouraged for tutorial and technical presentation topics:

- **Cyber and Electronic Warfare T&E**
  - Cybersecurity Offense and Defense
  - Newest Tools for Software Testing
  - Test and Evaluation Methodologies
  - Threats and Requirements
- **Directed Energy (DE)**
  - DE T&E History
  - DE Test Infrastructure and Instrumentation
  - DE T&E Safety
  - Policies and Procedures Governing DE T&E
  - Upcoming DE T&E Events
- **International T&E Challenges**
  - Detection
  - Environment
  - Global Threat
  - Successes of Testing Together
  - Synergies in Testing Together
- **Spectrum Technology**
  - Fully Networked Command, Control, and Communications (C3)

- Microelectronics
- Quantum Science (Encryption)

- **Test & Evaluation Science & Technology**
  - Autonomous Systems
  - Ballistic Missile Defense
  - Command, Control, Communications, Computer and Intelligence (C4I) Software
  - Cyber Security
  - Machine Learning / Artificial Intelligence (AI)
  - Space Defense / Offense
  - Spectrum Challenges
- **Testing Hypersonic Systems**
  - Acquisition
  - Capabilities
  - Challenges
  - Development
- **The Future Range**
  - Does the Future Range Accommodate all Joint Programs?
  - Live/Virtual/Constructive Testing
  - Maritime Testing (Surface & Sub-Surface T&E Challenges)
  - Network Integration Outlook
  - Range Interconnectivity
  - Replacing the Aging Infrastructure
  - What does the Future Range look like?
- **Threat Picture**
  - Counter Control Measures
  - Gap Analysis
  - Representation Gap
  - T&E Requirements Forecast
  - T&E Models

Presentations on any of these topics should be very informative. And, the mix of acquisition and T&E professionals with warfighters should generate very interesting conversations. Early registration ends on 12 September 2019, and early ITEA Member registration is only $495. If you are not a member, becoming a member will save you more than the membership cost by registering for just this one event. I hope to see you all there! ❑

STEVEN GORDON, Ph.D., is the Orlando Field Office Manager and a Principal Research Engineer for Georgia Tech Research Institute. He retired from the Air Force in 1998 and served as the first Technical Director for the Air Force Agency for Modeling and Simulation. Dr. Gordon has a Bachelor's Degree in Mathematics (Marymount); Master's Degrees in Education (Vanderbilt), Industrial Engineering/Operations Research (Purdue), and Business (University of Florida); and a Ph.D. in Aero and Astro Engineering (Purdue). This will be his last year as the Editor-in-Chief of The ITEA Journal of Test and Evaluation.

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Lessons from Past Rapid Acquisition Programs

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The United States has been actively engaged in combat for the past two decades. In response to warfighters' needs, the Department of Defense (DoD) has rapidly fielded many systems, including a wide range of countermeasures, weapons, and vehicle and aircraft armor upgrades during this time. A variety of programs across all service branches were reviewed to glean lessons from past rapid acquisition programs; many of these lessons also can be applied to future programs as recommended best practices. Six lessons emerged, representing themes common across multiple programs. The first lesson shows that the Department of Defense has the ability to field systems rapidly when needed. Lessons two through five pertain to specific techniques for success in rapid acquisition programs. The last lesson highlights that rapid acquisition strategies are not always successful for some programs. Case studies are used to illustrate these lessons.

Introduction


Lindsey A. Davis, Ph.D.

In the past twenty years, the United States has been actively engaged in combat and has fielded many systems rapidly. Examples include a variety of countermeasures, weapons, and survivability upgrades to aircraft and ground vehicles. In this study, programs were reviewed from all US military service branches and included systems from the past twenty years that had been fielded rapidly (typically within two years). Most of those programs had arisen in response to Urgent Operational Needs Statements (UONS), though some were incremental upgrades to existing programs intended to fill capability gaps.

Several lessons emerged from this review of past programs and are presented in this paper. Some of these lessons can be applied as best practices for future programs as well. These recommendations are relevant to acquisition of a variety of systems both within the Department of Defense (DoD) and external to DoD. The recommendations presented in this paper are not one-size-fits-all blanket recommendations, however, and should be considered on a program-by-program basis.

The six lessons are the following:

1. DoD can field systems rapidly;
2. Initial testing prior to fielding is informative;
3. Combining tests with non-conflicting objectives into one event can maximize efficiency;
4. Reviewing past testing on similar systems is worthwhile;
5. System development can continue after initial fielding; and
6. Rapid acquisition strategies are not always successful.

The first lesson shows that the DoD has the ability to field systems rapidly when needed. Lessons two through five pertain to specific practices and techniques to help ensure success in rapid acquisition programs. The last lesson is one of caution—although rapid acquisition strategies can work well for some programs, success is not guaranteed and compromises may need to be considered in some cases.

Each lesson is illustrated by a single case study, although many additional studies are available. Also, more than one lesson sometimes can be seen in a case study. In such instances, any additional lessons are noted as well.

Lesson 1: DoD Can Field Systems Rapidly

There are many concerns about the time it takes DoD to field systems, but the fielding process is not always lengthy. One classic example is the Mine-Resistant Ambush-Protected (MRAP) Family of Vehicles (FoV). MRAP vehicles were developed to provide protection against improvised explosive devices (IEDs) in

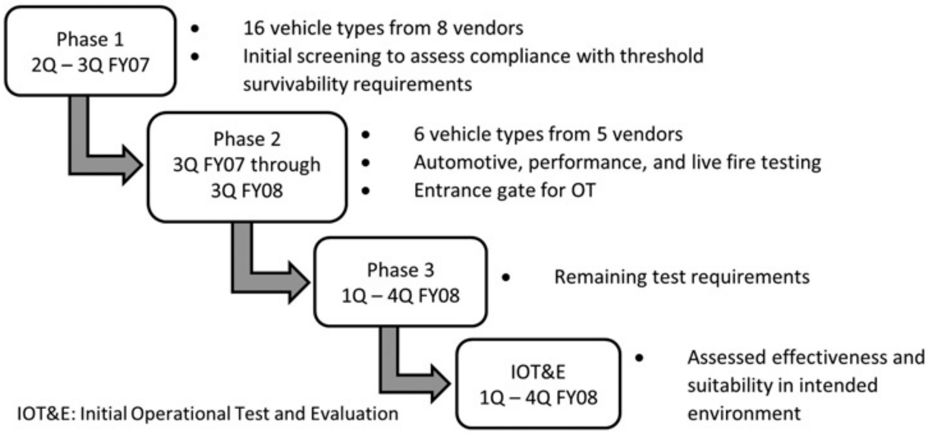

Figure 1: MRAP test structure

Iraq and Afghanistan. There are three MRAP FoV categories and multiple vehicle types within those categories: category I vehicles are smaller and carry six passengers; larger category II vehicles have a capacity of ten passengers; category III vehicles provide mine and IED clearance operations.

In late 2006, in response to a Joint Urgent Operational Needs Statement (JUONS), the DoD began the acquisition process for more than 1,000 MRAP vehicles (Friedman et al. 2013; Gansler et al. 2010). The first vehicles were delivered in theater in April 2007, less than six months after the initial contracts were signed (Friedman et al. 2013; Gansler et al. 2010). Less than two years after the initial contracts were awarded, the program was worth more than $22 billion and 15,000 vehicles had been purchased, with more than 6,600 of those vehicles already fielded (GAO 2008).

The acquisition process for MRAP vehicles has been unlike any other within the past fifty years. In May 2007, the Secretary of Defense announced that the MRAP program was the most important acquisition program within DoD and approved a "DX" rating for industry, which requires that MRAP contracts take priority over other contracts that lack this rating (Gansler et al. 2010; U.S. Government Accountability Office [GAO] 2008). This program moved extremely fast and supplied a lot of vehicles quickly. Unlike most programs, the MRAP schedule and budget allowed for concurrent production, testing, and fielding so as to accelerate the overall process.

The testing was structured to rapidly identify and field multiple viable solutions from multiple vendors. As shown in Figure 1, the testing occurred in phases and focused on the expected theater of operations and expected mission types. Phase 1 of testing consisted primarily of threshold-level underbody blast tests to ensure MRAP vehicles provided the desired level of protection against IEDs. This initial phase eliminated three vendors and ten vehicles from the program due to poor performance, highlighting the importance of conducting testing prior to fielding (see Lesson 2). Only five vendors were able to produce vehicles that passed this first stage of testing and all of those vehicles continued to the second stage of testing. This test structure resulted in multiple vendors developing the different variants of the MRAP vehicles, but DoD acknowledged that multiple vendors would be able to produce the desired volume of vehicles desired more quickly than a single vendor. However, this arrangement meant that there was little commonality between each MRAP variant, complicating training and maintenance within the MRAP FoV (GAO 2008).

Subsequent phases examined threats beyond threshold-level underbody blast testing, automotive and performance testing, and operational testing. Many of the tests were conducted too late to inform design changes for the first vehicles being fielded to Iraq and Afghanistan. Fielding some vehicles quickly came at the cost of retrofits and future design changes to address problems identified in later phases of testing.

Lesson 2: Initial Testing Prior to Fielding Is Informative

When warfighters need systems urgently, there is an inclination to cut out steps in order to speed up the acquisition process. Some may argue that testing of a system is not necessary or can be conducted after initial fielding. However, a limited scope of initial testing conducted before initial fielding always yields valuable information and is recommended for all systems prior to fielding.

An emerging submarine threat prompted the Navy to issue a UONS in March 2010. Two torpedo programs attempted to address the threat with software changes and minor hardware changes to existing torpedoes. The heavyweight Mk 48 torpedo is the only anti-submarine warfare and anti-surface ship warfare used by submarines. Similarly, the lightweight Mk 54 torpedo is the primary antisubmarine weapon used by surface ships and aircraft. Both of these torpedoes are general weapons that are not optimized to defeat any one specific threat; instead, they are designed to target as many different threats as possible and may not be ideal weapons to combat the threat identified in the UONS (Director, Operational Test and Evaluation [DOT&E] 2011a, 2011b).

Although both programs were already in planning to conduct operational testing, they shifted plans to meet the UONS and conducted Quick Reaction Assessments (QRAs) prior to early fielding. The QRAs included some hardware-in-the-loop modeling and simulation and some limited in-water firings (DOT&E 2011a, 2011b). The in-water firings on the Mk 54 identified a significant issue that needed to be fixed prior to fielding (DOT&E 2011b). Additional testing was performed to verify that the problem had, in fact, been solved. No problems were found for the Mk 48, but this limited set of initial tests was still worthwhile for both programs for the information it provided. Performing tests that confirm the system works as expected should not be discounted. Verifying that the system works as intended is still informative because it confirms the expected result. After the QRAs were completed, both systems continued with the full scope of operational testing initially planned prior to the UONS.

Some initial testing should be conducted prior to fielding. This testing can be limited to the immediate concerns (i.e., testing only the intended environment, mission types, and threats) to minimize the amount of testing that needs to be conducted prior to fielding. However, a full scope of testing (including all environments, missions, and threats) should be conducted, even if it occurs after the initial fielding. These later test results can inform subsequent designs; provide valuable information for adjusting the tactics, techniques, and procedures; and allow the services to fully understand the capability of the system.

Lesson 3: Combining Tests with Non-Conflicting Objectives into One Event Can Maximize Efficiency

An efficient test design optimizes the amount of information gained by using the shortest amount of time and the least amount of resources. One way to optimize a test design is to combine tests that could be conducted separately into one test event. For this to work, the objectives of each test must not interfere with each other. Determining whether tests have conflicting objectives must be done on a case-by-case basis and may require guidance from subject matter experts. In some cases, combining multiple test events may not be feasible. For instance, an operational test designed to get Soldier feedback on a new ground vehicle cannot be done in conjunction with a test to determine the survivability of that same ground vehicle against IEDs. When test objectives are non-competing, combining events may increase efficiency without sacrificing test objectives.

The Army Tactical Missile System (ATACMS) is a family of long-range precision missiles with a capability of reaching distances up to 300 kilometers. An aging ATACMS stockpile has created a capability gap. The Army's long-term solution is to develop and field the Precision Strike Missile (PrSM), but the PrSM is not expected to be fielded until 2022-2023. In the meantime, the Army is updating ATACMS to fill this capability gap. The ATACMS Service Life Extension Program (SLEP) converted the M39/M39A1 ATACMS with anti-personnel and anti-materiel bomblets into the M57 ATACMS, which has a unitary warhead. The ATACMS Modification program then added a proximity sensor on the M57 ATACMS to create the M57E1 ATACMS, which regains some area effects capability. M57E1 ATACMS missions include long-range point or area targets, as well as high-value targets, without the risk of unexploded submunitions (DOT&E 2018).

The Army had a limited number of missiles planned for the overall ATACMS Modification test series and optimized the use of the allocated missiles by adding more targets to the operational test events than typically used. Instead, if the Army had conducted separate tests, they would have had to choose which subsets of data to collect or would have had to use more missiles. By adding multiple targets to the test events, more data were collected in a shorter time using fewer missiles. In this case, the rapid acquisition process fueled innovative test designs that can be used on similar systems in the future, even for programs not on a rapid acquisition timeline.

Although the example discussed in Lesson 2 shows that testing may need to continue after fielding, the example in this lesson shows that continued testing is not always needed. Because previous versions of the ATACMS had been tested, a large scale of operational and live fire testing was not necessary in this case. The testing in this example was limited to the additional proximity sensor only, and all testing was conducted prior to fielding.

Lesson 4: Reviewing Past Testing on Similar Systems Is Worthwhile

There are many common systems or types of systems used in DoD, both within the same service and across the services. These categories can be as broad as ground vehicles or as specific as the precise countermeasure system implemented on certain aircraft. Reviewing system test strategies and test results can provide valuable insights that can be used in subsequent testing of other similar systems. For example, the methodology used to test ground vehicles should be consistent across vehicles and across services. Similarly, reviewing previous testing of a system integrated on several platforms can provide insights into the expected performance on future platforms. Often, DOT&E can provide valuable information about different systems because of its oversight of a variety of programs across the services.

Consider as an example the Department of the Navy (DoN) Large Aircraft Infrared Countermeasures (LAIRCM) system, a defensive system designed to protect against infrared guided surface-to-air missiles. The Advanced Threat Warner (ATW) upgrade added improved threat detection and notifications to the crew. The DoN LAIRCM ATW system was first tested during the follow-on test and evaluation (FOT&E) of the DoN LAIRCM program on the CH-53E heavy-lift helicopter from December 2014 through July 2015 (DOT&E 2016b).

In March 2015, the US Special Operations Command issued a JUONS based on an emerging threat. This prompted the Army to consider adding the DoN LAIRCM ATW to the Army Apache AH-64E, UH/HH-60, and CH-47 rotary-wing aircraft (DOT&E 2018b). This case study discussion focuses on the integration on the AH-64E platform.

The Army had planned to install the DoN LAIRCM ATW on the AH-64E as a stopgap measure until they could develop their own program that was better suited for use on Army rotorcraft. Because the Army viewed this installation as a stopgap measure only, they intended to install DoN LAIRCM ATW as an add-on system to the AH-64E, with minimal platform integration.

Initially, the Army was planning to conduct basic verification testing of the DoN LAIRCM system. DOT&E, however, helped the Army take advantage of data from previous testing the Navy had done during the FOT&E of the CH-53E. By leveraging this past test data, the Army was able to devote its resources to conducting testing specific to the integration of the DoN LAIRCM ATW system on the AH-64E (DOT&E 2016a).

This is a good example of rapid acquisition working well. The Army used data from past tests to avoid repeating the same or similar tests, the testing that was conducted was thorough and adequate to assess the system in the expected environments, and testing and fielding were completed on time. One additional factor that contributed to the rapid fielding of this system is the Army's simplicity in using an off-the-shelf system and performing little integration on their platform. It is easier to field systems rapidly when they require minimal system development and integration because fewer problems typically are found during testing.

Lesson 5: System Development Can Continue After Initial Fielding

Rapid acquisition strategies can be viewed as a mechanism for fielding programs rapidly. Instead, they should be viewed as a mechanism for fielding capabilities rapidly. The distinction is that the services may be developing a system that will take longer to field as compared to a simpler system that may be able to provide capability to the warfighter more quickly. Although this is not true for all systems, in some cases it is beneficial to focus on providing a basic capability to warfighters quickly while continuing development of an improved solution.

Consider the Guided Multiple Launch Rocket System (GMLRS) Unitary, which was designed as a supplement to the GMLRS Dual-Purpose Improved Conventional Munition (DPICM). GMLRS DPICM spreads its effects over a large area, often with a high dud rate and resultant unexploded ordnance (UXO). Adding a unitary warhead to the GMLRS rocket gave the Army an option to achieve effects in more limited area and reduced the chance for collateral damage.

Incremental changes to the GMLRS enabled rapid fielding of an initial, first-order solution and subsequent fielding of an improved solution. In 2005, the Army fielded the GMLRS Unitary Urgent Materiel Release (UMR) rocket. This rocket had a unitary warhead with a delay fuze and a point-detonating fuze. In 2009, the Army fielded the full-rate-production rocket, which added a proximity sensor that could be used to target a wider area, including personnel (Pincoski 2007).

Both varieties of these rockets have been used extensively in combat. The UMR rocket was used more than 1,000 times between the initial fielding in 2005 and December 2008, prior to the FRP rocket fielding. By 2017, more than 6,500 total rockets (both varieties) had been fired. By reducing the complexity of the initial rocket, some capability was fielded to the warfighter quickly, with additional capability coming later.

Lesson 6: Rapid Acquisition Strategies Are Not Always Successful

The DoN LAIRCM ATW system was described previously as an example of how rapid acquisition can work well. The previous case study discussed the integration of the DoN LAIRCM ATW system on the Army AH-64E; this case study discusses the integration of the same DoN LAIRCM ATW system on the Marine Corps MV-22 aircraft platform. The case study presented here shows how things can go wrong, even with the same system. Comparing this rapid acquisition strategy to that of the Army on the DoN LAIRCM ATW integration on the AH-64E provides valuable insights into key decisions that can impact the speed of acquisition.

In 2013, the Marine Corps began planning to add the DoN LAIRCM ATW system on the MV-22; this was two years before the JUONS was issued that prompted the Army to add the system to the AH-64E. In spring 2014, the Marine Corps issued an Urgent Universal Needs Statement (UUNS) to rapidly field the DoN LAIRCM ATW system on the MV-22 within two years. The Marine Corps was planning to add the DoN LAIRCM ATW system as a program of record and wanted to fully integrate the system with the mission system software on the MV-22 (DOT&E 2016a).

The Marine Corps did not reduce the scope of their rapid fielding efforts as compared to the program of record. They still planned to fully integrate the DoN LAIRCM ATW system, despite the UUNS and the JUONS. The system integration was not straightforward and many problems were identified, such that the MV-22 integration with DoN LAIRCM ATW took four years from the initial UUNS to complete. In fact, the Army was able to successfully field the DoN LAIRCM ATW system on the AH-64E prior to the Marine Corps doing the same on the MV-22, despite the fact that the Marine Corps initiated their efforts two years before the Army did.

A rapid acquisition initiative may not field new capabilities any faster than the full acquisition process. While the Marine Corps issued an UUNS, that alone did not make the acquisition process any quicker. In some programs, the acquisition strategy may need to be adjusted to ensure rapid fielding. In this case, if the Marine Corps had planned to field the DoN LAIRCM ATW system on the MV-22 initially with minimal system integration, it is possible that the Marines may have had the capability sooner. The Marine Corps then could have continued their efforts to work on the full integration of the DoN LAIRCM ATW system on the MV-22 and fielded aircraft with this full capability later.

Conclusion

Many people within DoD have expressed interest in speeding up the acquisition process. For many programs, this can be accomplished by considering the lessons and best practices presented in this paper. Thus, some testing, even if limited in scope, should be conducted prior to the initial fielding. Initial testing always provides useful information and may help identify problems that should be fixed prior to fielding.

Also, it is always important to strive for efficiency, but it is especially important when planning to test and field systems rapidly. One method to increase efficiency is to combine tests, where possible. Systems that require significant development or integration are more likely to have problems during testing, which could lead to program delays. To offset this, it may be necessary to simplify the system so as to field some capability quickly, while continuing to work on and subsequently field the improved solution.

Finally, rapid acquisition strategies should be geared toward fielding a capability to warfighters that is currently unavailable, rather than focusing on specific program goals and timelines. Considering these lessons from past rapid acquisition case studies also can be helpful when planning future rapid acquisition strategies. ❑

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Test in the Age of Agile:
Rising to the Challenge of Agile Software Development

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"The best way to get a project done faster is to start sooner."
– Jim Highsmith (Agile Manifesto signatory)

Agile software development is an iterative, incremental, and evolutionary approach to managing software development that is relatively common in the commercial sector. With the objective of reducing development time and responding to changing requirements on faster cycles, military programs are increasingly adopting Agile as part of their acquisition strategy. Adapting Agile methods for military systems, which often have unique requirements, requires careful consideration and a shift in traditional test and evaluation methods. This paper describes the challenges of test and evaluation of Agile software and suggests several ways of addressing those challenges, including embedding testers with development teams. A cautionary note regarding the criticality and complexity of military systems is offered along with the importance of safe, effective, and efficient tools for risk management. We include examples and lessons from the test and evaluation of several Air Force Agile software projects.

Introduction

The single greatest loss of life for coalition forces in Desert Storm was due to a software flaw that was insufficiently tested. On February 25, 1991, an Iraqi SCUD missile hit the 475th Quartermaster barracks at Dhahran, Saudi Arabia, killing 28 and wounding another 100 soldiers.[1] Patriot missiles launched to intercept the inbound SCUD missed the intercept due to a range gate error caused by the accuracy limits of the internal clock. The "clock," an incremental counter that counted every tenth of a second since the system was turned on, only used a 24-bit register for timing. At the time of the attack, the Patriot battery had been operating continuously for more than 100 hours, saturating the 24-bit register counter. Prolonged operations was an endurance condition that had never been tested since the Patriot was designed as a mobile system and was expected to restart every couple of hours. Twenty-five years later, the risk of insufficient software testing is a challenge that the Test and Evaluation (T&E) community must meet as the Department of Defense (DoD) moves increasingly to Agile Software Development (ASD) practices.


Col Douglas P. Wickert, Ph.D.

Agile Software Development, commonly contracted to 'Agile' (and usually capitalized[2]), is an iterative and incremental approach to software development. It is typically implemented through small, collaborative, self-organizing, cross-functional teams. Modern ASD emerged out of several different product management theories in the late 1990s including Scrum, Lean, Kanban, Rapid Application Development, and Extreme Programming.[3] Agile was encapsulated in the Agile Manifesto, a set of four values and twelve principles signed by seventeen software management theorists at a retreat in Snowbird, UT, in 2001 (*Table 1*).[4] Since then, Agile as a management structure has further evolved into a wide variety of methods and practices self-described as Agile including Scrum, ScrumBan, Scrum/XP, Kanban, Scaled Agile Framework (SAFe), and Extreme Programming (XP) to name a few of the more common categories. DevOps (and DevSecOps) are more recent manifestations of Agile in which development and operations (or development, security monitoring, and operations) are combined to run concurrently with close integration and collaboration between developers and users. The values

Table 1: Agile Manifesto Values and Principles

Values of the Agile Manifesto			
value more	Individuals and interactions…	over	…processes and tools
	Working software…	over	…comprehensive documentation
	Customer collaboration…	over	…contract negotiation
	Responding to change…	over	…following a plan value less

Twelve Principles of Agile Software	
1. Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.	7. Working software is the primary measure of progress.
2. Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.	8. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
3. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.	9. Continuous attention to technical excellence and good design enhances agility.
4. Business people and developers must work together daily throughout the project.	10. Simplicity – the art of maximizing the amount of work not done – is essential.
5. Build projects around motivated individuals. Give them the environment and support they need and trust them to get the job done.	11. The best architectures, requirements, and designs emerge from self-organizing teams.
6. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.	12. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

and principles of the Agile Manifesto are now also being widely adapted for management of non-software projects. A 2016 *Harvard Business Review* article by one of the original seventeen manifesto signatories highlights that agile management methods have spread from software development to a broad range of industries, functions, and "even into the C-suite."[5]

Since 2001, Agile has become a dominant approach to software delivery, at least in the commercial sector. With a few exceptions, the defense industry has continued to rely on a traditional, top-down "waterfall" approach—first codified by DOD-STD-2167 in 1985 but with earlier origins in the 1970s—in which requirements are cascaded down to define architecture, which is then coded, verified through testing, and validated in operational test (*Figure 1*).[6] Though now frequently maligned and much disparaged as creaking and archaic, the waterfall model is essentially system engineering applied to software. When closely examined, the real complaint against waterfall has little to do with waterfall itself and more to do with the nature of acquisition and the challenge of writing requirements in general. Agile excels in domains in which requirements are uncertain (Agile proponents claim that the requirements "emerge" through development) because flexibility and iteration permit the gradual development and definition of detailed requirements. In reality, the distinction between waterfall and ASD is not an absolute choice between mutually exclusive practices. Successful Agile projects depend on a stable development environment or functioning baseline before beginning the cycle of sprints that characterize ASD. For example, the Defense Innovation Board (DIB)[7] recommends approximately six months of development before initial fielding and the start of the "continuous delivery" phase which then runs on a recommended three-month release cycle.[8] Stable functioning baselines necessarily need some level of architecture design and systems engineering, i.e., a waterfall.[9] On the other hand, nothing in waterfall precludes incremental or iterative delivery. A decade before Agile was a buzzword in commercial software, using incremental delivery to reduce risk in defense software was not unusual: "To mitigate downstream test risks, TRW has defined an incremental test approach that satisfies TRW and Government objectives for development/integration testing and for formal requirements verification… [that] conforms to DOD-STD-2167A standards."[10] A 1987 Defense Science Board report on military software included a section discussing "rapid prototyping and

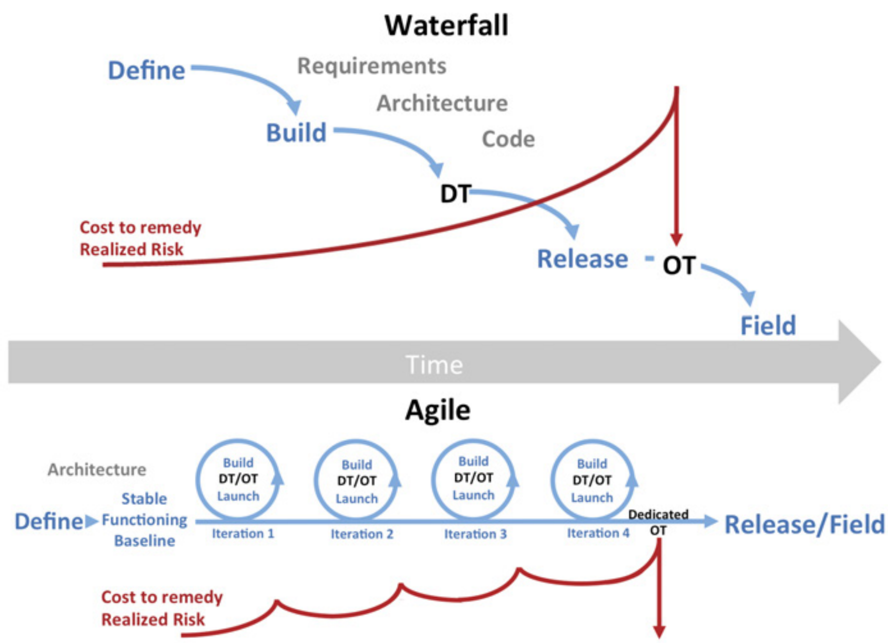

Figure 1: Comparison of Waterfall (top) and Agile (bottom)

iterative development" technology.[11] *That which is done is that which shall be done: and there is no new thing under the sun.*[12]

Although speed was not an explicit principle behind the Agile Manifesto, most commercial and government projects that adopt Agile for software development do so because they expect it to be faster.[13] A 2017 survey of the commercial software industry found that 75% of teams that had adopted Agile management methods did so in order to accelerate software delivery.[14] The DIB's recommendation to adopt Agile is based on the claim that "faster reduces risk by focusing on the critical functionality rather than over-specification and bloated requirements."[15] But Agile is not a panacea. A different 2017 IT industry report, which surveyed 300 US and UK Chief Information Officers (CIOs), found that one-third of Agile projects fail to some degree.[16] Over half of the surveyed CIOs considered Agile "discredited" and an "IT fad." The most common complaints from CIOs against Agile were uncertain timescales; inadequate planning; insufficient documentation ("Agile has been interpreted as a license to abandon the discipline of project documentation."); and ignoring non-functional, enterprise-wide requirements (security, accessibility, system resilience).[17]

The purpose of this article is not to argue for or against Agile in defense systems. Directed by the FY18 National Defense Authorization Act and encouraged by the DIB's Software Acquisition and Practices (SWAP) study, the DoD is pursuing streamlined software development. Given a record of delays, cost overruns, and poor performance in several DoD software acquisition projects, there is clearly ground for improvement. The DIB explicitly recommends the Services adopt Agile based on their finding that "at the present time, DoD's software prioritization, planning, and acquisition processes are among the worst bottlenecks for deploying capability to the field at the speed of relevance."[18,19] The Air Force has prescribed Agile Software Development as a requirement for all new programs unless waived by the Milestone Decision Authority.[20] The first two recommendations of a 2018 Defense Science Board (DSB) report were 1) for the Services to establish criteria for software factories, and 2) to adopt continuous iterative development for software.[21] The Air Force has embraced these recommendations by creating the Kessel Run and Kobayashi Maru software factories to support programs under the Digital Program Executive Office (PEO) (formerly the Battle Management PEO) and the Space Systems PEO respectively.

This article will examine tester involvement in ASD before highlighting the unique challenges of software testing in Agile frameworks. A special focus on criticality and complexity of military systems is emphasized. The Air Force T&E enterprise has addressed a number of the challenges of testing alongside continuous development by insisting on early tester involvement. The *Agile Software Development Test and Evaluation Guide*, issued by Air Force T&E in 2018, details several considerations and best practices for collaboration between managers, developers, testers, and users.[22] For good or bad, the Air Force and DoD are pursuing Agile Software Development and the T&E community needs to adapt to the unique challenges associated with testing in Agile and continuous development frameworks.

Agile and Early Tester Involvement

At the heart of Agile Software Development, at least as applied to commercial software products, is the notion that the development team should quickly and effectively adapt the software to user desires that may continuously shift and change. This is explicit in the second principle of the Agile Manifesto (*Table 1*). To be effective, Agile methods require a close relationship with the end user. For commercial software, this is done by inviting the end user to be part of the development team. Throughout development, the end user provides continuous feedback to guide further development and improvement of the evolving software. For a variety of reasons, this is difficult to achieve in military systems. A 2019 GAO review of DoD software acquisition for space systems found that early user engagement was mostly ineffective, contributing to significant cost overruns and extended development timelines.[23]

In commercial software development, the ASD developer typically tests their own code while soliciting user feedback on whether the software is doing what the user wants it to do. Because of the critical and unique nature of many military requirements (e.g., interoperability, cybersecurity, safety, effectiveness, suitability), the developer self-test and end-user feedback approach to test is inadequate. Developmental and operational testers who are knowledgeable in the evaluation of the unique requirements for military systems are essential. If a new webmail feature crashes when it is deployed to users, users may be inconvenienced but no one is likely to die from the failure. Military system function and reliability is a different matter altogether.

The commercial practice of embedding representative end users with software development teams is not directly analogous to military systems. Analogs to the specifically trained T&E experts in military operations do not exist in the commercial sector, so the developers rely on customer feedback of early software releases. Early tester involvement is the appropriate analog to early end-user engagement from commercial ASD. However, merely embedding end users with development teams, as done with commercial ASD, is insufficient for critical military systems which usually have unique military requirements. As an example, consider an airman who works in the Combined Air and Space Operations Center (CAOC) and is responsible for planning and tracking aerial refueling in an Area of Responsibility (AOR). Although this airman may be well-qualified for this particular role in the CAOC, the tanker-planning airman is unlikely to understand the very specific requirements for cybersecurity. Likewise, a single air battle manager (ABM) embedded with a software development team would be unable to rigorously conduct the volume, load, and fuzz tests necessary for evaluating the effectiveness of new software before it reaches the CAOC. Nor is identifying the end users of highly-integrated military systems non-trivial. An Air Force senior leader made this point explicit during a recent Kessel Run program review: the "end user" is the combatant commander and the performance metric that matters above all else is combat capability, not coding speed or cycle time.[24]

Early tester involvement, a cornerstone of Air Force Instruction 99-103, Capabilities-Based Test and Evaluation, is also a key enabler for realizing rapid acquisition or ASD. The Air Force's interim policy guidance on middle-tier acquisition states that "Early tester involvement, beneficial in any acquisition strategy, is particularly essential for rapid acquisition."[25] With several Agile projects, the Air Force has adopted the approach of embedding developmental and operational testers with the software development teams. For example, developmental testers from the 45th Test Squadron and operational testers from the 605 Test and Evaluation Squadron are continuously embedded at the Pivotal software factory in downtown Boston as part of the Kessel Run project. These testers are integral parts of the development team (*Figure 2*). Because trained testers are in high demand yet low supply, embedding testers with ASD teams strains limited test personnel and presents the T&E community with the first of several practical challenges to realizing effective ASD.

Agile Challenges to Test and Evaluation

Successful Agile development requires early and continuous tester and user involvement. Because multiple programs are being developed concurrently and the supply of testers and end users is limited, the availability of military testers and end users is a particular challenge for ASD. The availability of military end users is further constrained by the fact that they have a primary job (often in remote locations) that does not involve sustained support to software development. Testers are typically grown from the end-user community and can help close some of the end user participation gap, but tester availability for sustained support is also constrained by the volume of work testers have to do.

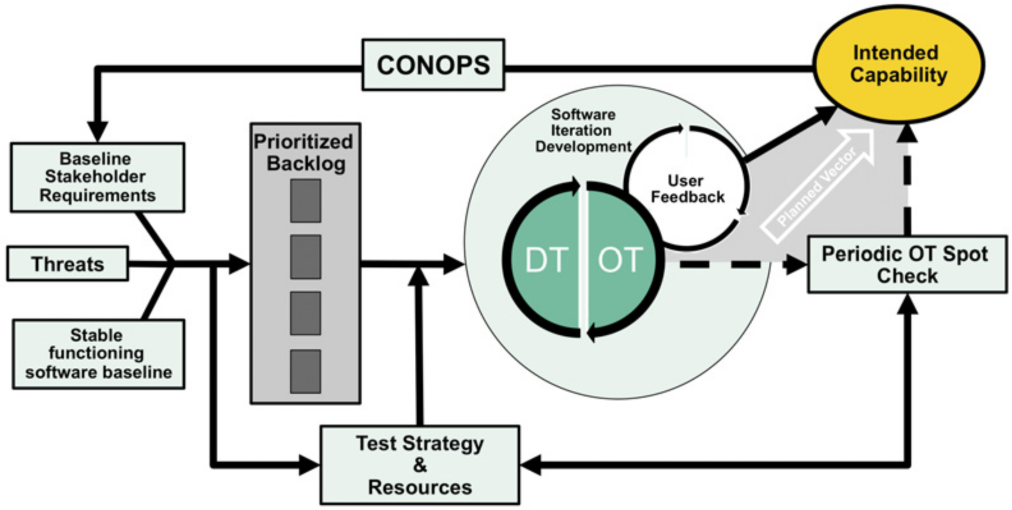

Figure 2: Embedding Testers in Agile Sprint Cycles

The second challenge of testing Agile is that not all software is the same and that the tools developed for Agile testing in the commercial sector are not immediately applicable to military systems. The spectrum of the "software zoo" runs from relatively simple applications (e.g., chat apps) to complex, highly integrated embedded and real-time systems (e.g., operational flight program (OFP) control laws) with a wide range of applications in between (search functions, document management, office automation tools, virtual reality, training devices, simulators, decision support systems, data warehousing, analytic/scientific processing, machine learning, and deep artificial intelligence). Other attributes that distinguish different types of software and systems include the level of user involvement (intense interaction or autonomous), volume of data, persistence of data, time criticality (from hard real-time to soft real-time, and from minutes to years), CPU intensiveness, processing distribution (local, location agnostic, or ubiquitous), update availability (24/7 monitoring systems without scheduled downtime), roll-back requirements, level of interoperability, number of unique interfaces, datalinks, and security. How you build, test, and deploy software depends on what software you are building.

The Agile Manifesto values working software over documentation. Although nothing in the Manifesto argues for zero documentation, in practice, developers commonly rely on user stories instead of established specifications or requirements. Extreme approaches to Agile, e.g., Extreme Programming, eschew any specification of requirements. The lack of detailed requirements and specifications presents a third challenge to testing Agile software. Testers must rely on their judgment and an understanding of the software architecture and backlog to develop test requirements informed by risk management (*Figure 3*). Without documentation, testers often have to build functional control diagrams from scratch to understand all states and flows through the software to ensure it has been completely tested. Determining requirements has never been easy: "The most difficult part of requirements gathering is not the act of recording what the users want; it is the exploratory, developmental activity of helping users figure out what they want."[26] An old software rule of thumb holds that three-quarters of software errors are requirements errors (leaving only a quarter of "bugs" as actual coding errors).[27] This has practical limitations to automated testing, which cannot catch requirement errors, a point we return to below.

A fourth challenge in the test and evaluation of Agile software is the tension between functional and "non-functional" requirements, particularly as they relate to measures of suitability. In waterfall development, program managers can effectively trade cost, schedule, and performance to address end-user needs. Since typical Agile projects establish a fixed schedule up front with set deliveries at the end of every sprint, performance is the only unconstrained parameter (resources are generally also fixed by small team sizes and scaling problems). As such, minimum viable products often do not or cannot address reliability, maintainability, interoperability, etc. Further into development as the technical debt inevitably builds in the program backlog, Agile

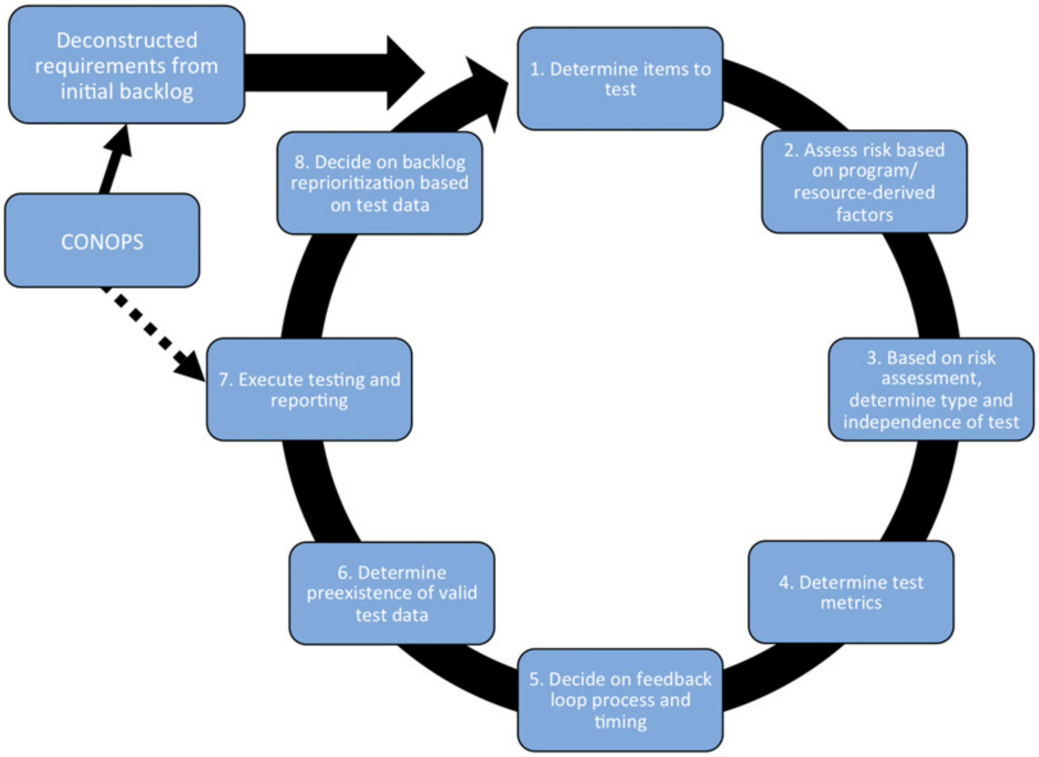

Figure 3: Software Iteration Test-Driven Events

projects tend to continue to prioritize the technical performance of functional features that the user desires over the non-functional. Operational testers can report poor performance on suitability measures, but these tend to persist in the backlog without being addressed. Some suitability measures, e.g., interoperability, can only be addressed up front during architecture design. This is discussed further with respect to system complexity considerations below.

Given these constraints and the wide range of software types, it should be obvious that all software is not appropriate for Agile development. Agile is most effective if functions or features are modular and can be delivered in increments.[28] Many military functions are not (new software for a radar warning receiver without a mission data file to go with it is useless). If individual modules or components cannot be deployed separately or do not have value to the warfighter, the software is poorly suited for incremental delivery.

There is no one-size-fits-all approach to software. The success of Agile in the commercial sector may not warrant a direct comparison to military systems. Indeed, much of the 'success' of Agile, commercial or otherwise, is purely anecdotal. The Defense Science Board admits as much:

> *There are no widely cited or authoritative empirical studies to support the thesis that Agile development practices are superior to Waterfall approaches. Even if there were such studies, they would likely be focused on commercial software and, thus, one might question whether those results would translate to the kinds of software systems that the DoD builds, which are often characterized by a real-time control requirement and a high-end security threat.*[29]

It is not expected that any of the concerns or challenges above will slow the DoD's commitment to Agile. This presents a final challenge of ASD that is more related to the choice of an appropriate acquisition strategy than to test and evaluation: applying Agile to software projects that are poorly suited to Agile. Because of their experience on previous projects, testers can often predict where programs will encounter problems. Testers are the ones to discover and report the flaws; the challenge lies in reporting deficiencies without the taint of smugness. Cautious skepticism is not cynicism or pessimism, though it can be perceived as such. To develop safe, effective, and efficient tools for meeting the challenges of testing Agile, the T&E community must see and work beyond the hype and magic thinking of Agile.

Testing Agile

Writing good software is hard. Testing software, good or bad, is even harder. Agile places a significant emphasis on automated testing. It is not uncommon to encounter Agile purists who insist that automated testing is the sole testing necessary before delivering software to the end user.[30] Many ASD approaches in the commercial sector, particularly those using DevOps, are built around the idea of automated pipelines. In a fully automated pipeline, pieces of code are unit tested using automated scripts and tools. Once a piece of code passes unit testing, it is continuously integrated into the larger ecology, delivered into production, and simultaneously deployed to users.[31] Amazon claims to release new software every 11.6 seconds.[32] If automated testing fails to detect a problem during continuous integration, the bug will be discovered in operations through user feedback. User complaints generate issues and error reports that are placed into the backlog for developers to address during a subsequent iteration and release.

The pace of DevOps in commercial software would not be possible without automated testing. Although no reasonable person expects deployment intervals for military software at rates comparable to commercial DevOps, automated test is an extremely valuable productivity tool. The DIB included automated testing in their ten commandments of software: "Automate testing of software to enable critical updates to be deployed in days to weeks, not months or years."[33] However, automated test alone is insufficient as not all tests can be automated. In the Air Force's Kessel Run project, manual testing by developmental and operational testers regularly reveals bugs that were not identified through automated testing.

ASD typically uses a test-driven development philosophy in which the automated test and code are written at the same time. Under the test-driven development framework, the code is written so that it will pass the test. If the test is not rigorous or complete, unsatisfactory, error-prone code will enter production. As noted above, automated tests cannot find errors in requirements which, as empirical data suggest, outweigh actual coding errors by a factor of three-to-one. Test-driven development can be improved through better or updated requirements (better interpretations of user stories in Agile), which in turn leads to improved tests. The test cards used in manual testing also become useful source documents for writing additional scripts for new forms of automated testing.

Software should also be subjected to performance and edge testing, much of which can be automated (*Figure 4*). Performance testing includes volume testing, load testing, and endurance testing. In volume testing, large amounts of data are used to stress the system, handling, and memory. Load testing and concurrency measure the effects and limits of multiple users employing the system simultaneously. Endurance testing, running the software for long, continuous periods of time without restarts, can reveal memory leakage, clock problems, and other issues. Edge testing includes both fuzz testing (a barrage of random inputs) and link path testing. To be complete and thorough, software should be tested in both software-in-the-loop and hardware-in-the-loop environments.

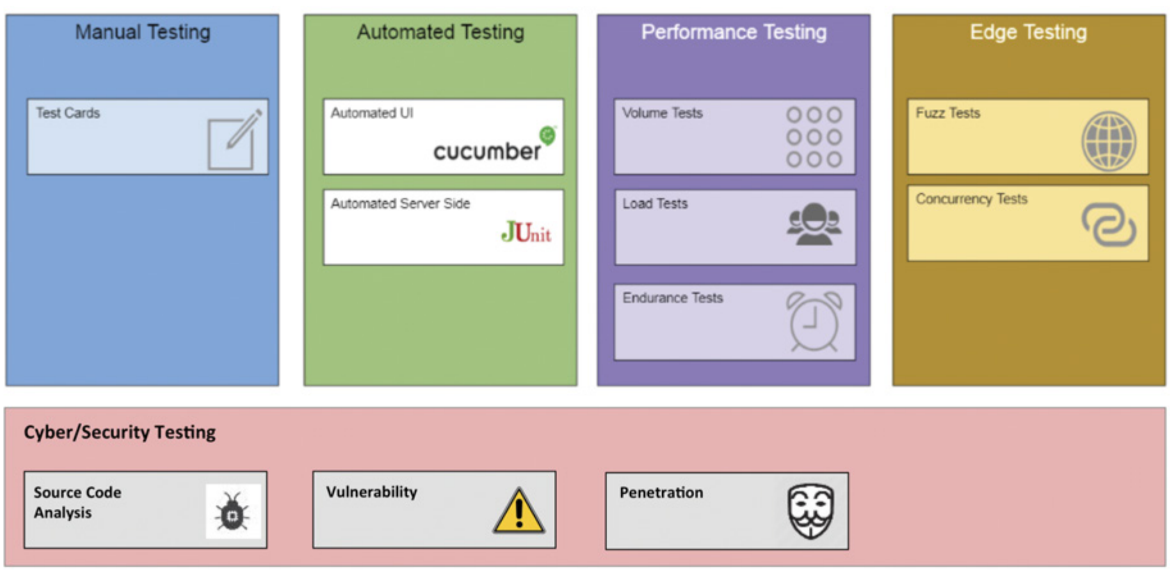

Figure 4: Types of test in Agile DevOps

With commercial software, "operational testing" can be achieved by deploying software to actual users. In the case of critical military software, testing software in actual operations is ill-advised. Military software should be tested in as operationally representative of an environment as possible. This includes hardware, bandwidth, latency, distribution, etc. Code that works fine in the developer's environment may be useless or dangerous when deployed to user systems.

Last but not least, Agile must address the full extent range of cyber and security requirements through rigorous testing. The more critical the system, the more rigorous the test criteria must be. Vulnerability testing can only be automated for known, existing vulnerabilities. Source code analysis is essential for revealing potential attack surfaces and requires specialized expertise. Penetration testing also requires specialized expertise which is hampered by the first challenge identified above, namely, a high demand for the limited number of software red teams.

The ultimate goal of testing is to ensure the delivery of effective and suitable capability to the warfighter. Test data by themself serve little value until they are evaluated with respect to how they will be employed. This requires a clear understanding of the concept of operations (CONOPS). Agile strategies often eschew defining up-front requirements in favor of letting requirements emerge during the course of iteration and user feedback on incremental capability. Regardless of strategy or level of documentation, it is absolutely essential that users clearly articulate their intended CONOPS before development starts. This is a subject we return to in the context of complexity.

System Complexity: Requirements, Architecture, and Systems Engineering

Agile is best-suited for simple systems. Complexity, a hallmark of many military systems, is the antithesis of simplicity. Though there are some military systems that are unnecessarily and gratuitously complex, many are complex by the multi-domain nature of the underlying mission. A complex system is formally defined as a network made up of a large number of nodes or components which interact with each other in unpredictable ways.[34,35] A feature of complex systems is that, due to the sheer number of interactions and possible states (i.e., the complexity) of the system, system-wide outcomes are difficult or impossible to predict from behavior or local attributes of individual nodes.[36]

This definition differs somewhat from the Agile Manifesto's perspective on simplicity. The Manifesto measures simplicity by "the amount of work not done," not by the nature of the possible system states. This matters beyond lexical comparisons. System complexity tends to continuously and inexorably increase, straining the ability to effectively conduct test and evaluation. Agile is not immune to the trends of increasing complexity. A well-known rule of software development, Wirth's law, states that "software systems grow faster in size and complexity than methods to handle complexity are invented."[37] MIT Professor Nancy Leveson, long an advocate for engineering safety into software and complex systems, offers a cogent warning against complexity:

> *We are designing systems with potential interactions among the components that cannot be thoroughly planned, understood, anticipated, or guarded against. The operation of some systems is so complex that it defies the understanding of all but a few experts, and sometimes even they have incomplete information about its potential behavior. Software is an important factor here: It has allowed us to implement more integrated, multi-loop control in systems containing large numbers of dynamically interacting components where tight coupling allows disruptions or dysfunctional interactions in one part of the system to have far-ranging rippling effects. The problem is that we are attempting to build systems that are beyond our ability to intellectually manage: Increased interactive complexity and coupling make it difficult for the designers to consider all the potential system states or for operators to handle all normal and abnormal situations and disturbances safely and effectively.*[38]

Complexity is inescapable. The best way to deal with complexity is through careful architecture design. Initial architecture decisions are software engineering decisions that are often expensive to change after the design has started. Agile purists argue that the architecture will emerge as developers iterate on the product (Principle 11, *Table 1*). Purists even oppose software system engineering approaches such as Big Design Up Front (BDUF) and Big Up Front Architecture (BUFA), which seek to establish a general architecture before starting development. Relying on organic architecture emergence may be suitable for some simple commercial applications, but it is inappropriate for military systems which are usually more complex and often comprised of multiple architectures. Agile does not eliminate the importance of systems engineering.

Although the DSB encourages reduced reliance on specification and documentation, they do insist that architecture still matters: "While full specifications should be eschewed, emphasis must be placed early on in a project to develop clear, complete, and easily communicated principles of operation. Initial builds with alternate architectures may help to gain sufficient understanding to make an informed choice of final architecture."[39] The DSB addresses concerns of complexity by urging the architect "to define modules in a way that avoids cross-couplings, whereby changes in one module impact and require changes to other modules. DevOps requires careful architectural design to avoid unintended complications by concurrent efforts. In general, this requires carefully defining the module and subsystem interfaces; thorough testing of interfaces is mandatory."[40]

Because complex systems are inherently difficult to analyze, they are also difficult to test. Test design requires a full functional understanding of how the system is designed (architecture) as well as an understanding of how it will be used (CONOPS). Upfront architecture design and a complete understanding of the CONOPS are necessary before embarking on development. This has two significant consequences for test and evaluation. First, because system behavior cannot be reliably predicted from the behavior, a subset of a complex system, component-level testing is not a reliable indicator of overall system performance or even that the component will behave in the same manner when it is part of the larger system. Component-level testing is still important, but results should be weighed with healthy skepticism. Thus, the end-to-end, operational test in an operationally representative environment becomes particularly important for complex systems. Second, because the number of possible states of a complex system grows factorially large, the operational assessment is never really complete. Complex systems must be continuously monitored over time, something for which Agile is well-suited due to the close integration of users, developers, and testers.

Conclusions

"The current approach to software development is a leading source of risk to DoD; it takes too long, is too expensive, and exposes warfighters to unacceptable risk."[41] So begins the Defense Innovation Board report that encourages the prioritization of software development, the adoption of DevSecOps practices, and a culture that prioritizes speed as a critical metric. The Test and Evaluation community has a critical responsibility to ensure that speed is vectored in a direction that serves the needs of the warfighter. "Fail fast is an intoxicating prospect but in practice, it can blur the distinction between continuous improvement and genuine failure. How do you know when a project is actually on the road to ruin? You may be iteratively improving, one failure at a time, towards the wrong outcome."[42]

A new focus on Agile attempts to address DoD's poor track record on software. The Defense Innovation Board acknowledges that "Agile is a buzzword of software development, and so all DoD software development projects are, almost by default, now declared to be 'Agile.'"[43] With nearly every project seeking to brand itself Agile, it is difficult to separate true innovation from hype and fad. Agile purists who imagine themselves in a jihad against waterfall, denouncing independent test as needless bureaucracy, exacerbate the challenge. But such views are not part of the original spirit of the Agile Manifesto. In the words of Jim Highsmith, one of the original seventeen signatories:

> *The Agile movement is not anti-methodology, in fact many of us want to restore credibility to the word methodology. We want to restore a balance. We embrace modeling, but not in order to file some diagram in a dusty corporate repository. We embrace documentation, but not hundreds of pages of never-maintained and rarely-used tomes. We plan but recognize the limits of planning in a turbulent environment.*[44]

In his widely influential and frequently cited 1986 essay, "No Silver Bullet—Essence and Accident in Software Engineering," Fred Brooks[45] argued that "there is no single development, in either technology or management technique, which by itself promises even one order of magnitude improvement within a decade in productivity, in reliability, in simplicity."[46] The things that are hard to do will still be hard, regardless of how we approach them. Software is no different. To rapidly deliver effective capability to the warfighter, testers need to get involved with projects at the earliest possible time, regardless of how they are labeled. Debating what is or what is not Agile misses the point of the first principle of the Manifesto: "Our highest priority is to satisfy the customer [warfighter]."[47]

Even as the test community responds to new approaches for managing software development, the landscape will shift. Meeting the challenges of Agile Software Development outlined above is not the end of the challenge. Systems under test will become more complicated and increasingly software dependent. System complexity will inexorably increase and integration and interaction will grow deeper. Systems-of-systems architectures will become more pervasive. Our overall reliance on software is unavoidable. All this will couple with new fads and ideas in management to create new and significant challenges for Test and Evaluation. If we are to avoid failures such as the Patriot glitch that killed dozens and wounded far more, the Test and Evaluation community must remain committed to its core responsibility. Test and Evaluation is the means by which we ensure the safety of the systems we create as well as characterize their performance in representative environments. The fate of the warfighter and the success of the mission depends on Test and Evaluation to perform this vital function. The new focus on Agile challenges T&E in new ways, but the Test and Evaluation community is adaptable and will doubtless respond. It is too important not to. ❑

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Acknowledgments and Disclaimer

The views expressed are those of the author and do not reflect the official policy or position of the US Air Force, the Department of Defense, or the US Government. This material has been approved for public release and unlimited distribution.

Endnotes

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14 Version one 12th Annual State of Agile Report.

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Self Service Infrastructure Environment for Next Generation High Performance Test and Evaluation (T&E)

Self Service Portal for Test and Evaluation Infrastructure Life Cycle Management, Provisioning, and Orchestration of "Layer 0" (PCIe) through Layer 7

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Introduction


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Test and Evaluation (T&E) High Performance Compute Centers are expanding throughout major industries as the need for the computational power across larger data sets and workflows grows exponentially. Lower barriers of entry and higher performing centers are accounting for the bottleneck throttling the adoption of workflows in these Compute Centers. With the advent of technology breakthroughs in the interconnect backplane technology based on industry standard PCIe *(Peripheral Component Interconnect express)* interface, to solve latency and bandwidth limits, and Lab as a Service automation frameworks, Test and Evaluation Compute Centers can solve both of these issues. Test Centers with a focus on "as a Self Service" portals to schedule, reserve, and configure new, faster, and greener network infrastructure will allow more users to adopt and consume resources and deliver solutions to high compute and big data test and evaluation problems at a new pace.

The key to the successful deployment of Test and Evaluation Compute Centers as a Self-Service (TECaaSS) is based on Lab as a Service frameworks combined with automation tools to provide a wide range of provisioning and orchestration automation linking the workflow to the infrastructure. The ability to disaggregate and aggregate the network, compute, memory, and storage items (i.e., Layer 0 interconnect) into unique stacks for specific workflows, while being managed as a life cycle sandbox will allow users to more efficiently consume the Test and Evaluation Compute resources.

This article will address the problems facing the Test and Evaluation Centers (TEC), solutions to the problems, risks, and an example solution using the latest available set of tools and methodologies to accomplish the goal of delivering Test and Evaluation as a TECaaSS.

Test and Evaluation High Performance Computing Center Usage Barriers

Test and Evaluation High Performance Computing (HPC) Center environments encompass a number of different types that share some common characteristics, but also have their own unique requirements.

HPC Is a Changing and Challenging Data-Driven Environment

The remarkable increase in the amount of data being collected that must be analyzed and stored is driving the rapid adoption of advanced data analytics and Artificial Intelligence (AI) that is challenging the fundamental architectures of today's ASC data centers in a way not seen since the 1990s.

AI and the associated Machine Learning (ML) and Deep Learning (DL) applications are fueling demand for fundamental change in the creation of compute and storage clusters. Faster and larger storage arrays and a rapid proliferation of specialized compute accelerators, like GPUs (Graphic Processor Units), FPGAs (Field Programable Gate Array), and custom ASICs (Application Specific Integrated Circuit), are creating bottlenecks and configuration problems for the interconnect systems, as the traditional networks were never designed to handle the performance requirements of these workloads and devices.

Further, the rapid pace of change in acceleration technology and AI software fuels the necessity for flexible and easy to upgrade architectures, capable of incorporating new technology without demanding forklift upgrades to expensive equipment. This means disaggregating elements of the traditional server into separate pieces that can be easily shared. But, in order to effectively disaggregate storage and accelerators, the interconnects must support both an exceptionally low latency AND high bandwidth.

And, of course, data center managers want to drive high utilization of expensive new storage and acceleration products to keep both Capex and Opex costs down.

Add all these up and these Advanced Scale Computing, Enterprise, Cloud, and Edge data centers need both scale-up and then scale-out resources across the cluster and require a network technology that will grow in both directions.

Two potential solutions both raise new issues. Scaling-up computing systems into ever-larger "super-servers" is generally cost prohibitive for all but the largest academic or government institutions. Scaling-out computer power by replicating servers introduces overprovisioning and underutilization inefficiencies.

A few IT technology industry efforts, stated below, are aimed at overcoming these issues:

- Numerous companies—from established to startup—are developing a new wave of more efficient, niche accelerators. Rather than general purpose GPUs, these chips work faster and use less power because they are designed for very specific processing tasks.
- Solid State Disk (SSD) storage providers are rapidly improving performance.
- Advanced Scale Computing (ASC) is disaggregating resources into a *composable infrastructure* where compute, storage, and accelerator resources can be accessed on-demand.

Although disaggregating resources is the right solution, now the system interconnect that enables composability becomes critically important. Insufficient speed and high latency in the interconnect networks create a bottleneck in scaling-up and scaling-out with ASC. The underlying question for customers then becomes: How can I best manage all these new compute, storage, and network resources to break the constraints of prepacked servers and scale my computing to meet changing requirements, while getting the best bang for my computing buck?

Addressing the Issues – Solutions for a High Performance Test and Evaluation Center Service

PCIe Based Interconnect Network

Starting with a fundamentally different architecture, a PCIe (Peripheral Component Interconnect express) interconnect network eliminates the bottleneck. This architecture can construct a multi-rack, composable infrastructure that performs as if every storage and compute element was inside a single box, providing many benefits:

- Native PCI Express (PCIe) communication between hundreds of mixed processing units, cutting latency by eliminating the entire translation layer required by other interconnect network options.
- True Direct Memory Access and sharing of *all* connected processors and memory with point-to-point connections between any two devices, reducing customer investment in these resources.
- Dynamically disaggregation and composable, scalable, and elastic infrastructure.
- A roadmap for end-to-end data speed improvements across the entire interconnect network.
- Legacy support for Test and Evaluation Compute resources.

Self Service Portal for TECaaSS

Many entities today are struggling with how to efficiently manage their infrastructure with the continuous pressure to reduce cost while increasing performance, capacity, and ease of use for their consumers. These entities have identified the following infrastructure management needs:

- Support of new technologies
  - New Interconnect for networking based on PCIe resources
- Scheduling, reserving, managing, deploying (life cycle) environments
- Auto provisioning of resources (physical and virtual)
- Supporting converged infrastructure and legacy hardware

  - Support of cross domains (public and private clouds)
- Automation Framework to control provisioning from PCIe thru Layer 7
- IT admin activities
  - Auto-discovery, lab resets, resource health-checks
  - Powering down devices when not in use
  - Support for maintenance modes on resources
  - Integrating Help Desk applications into the workflow of administration of the HPCC
  - Spinning up new resources on demand, etc.
  - Adding workload provisioning on top of the compute stack optimization of the provisioning and orchestration specific to the stack and the workload
- Supporting multiple tenancies and domains
- Configuration management of HPC resources
- Enabling user automation (configuring and deploying workloads, Virtual machines, containers, DevOps flows, sandboxing, etc.)
- Sharing of intellectual property
  - Support processes, automation, configurations, resources, use cases, etc.
  - Community based and open source focused
- Integration with other tools such Help Desk, Ticketing systems, and Simulators
- Metrics on the processes/activities, resources, usage, and users, to manage the life cycle of the environment.

This list is by no means complete but it does address the majority of the problems seen by these entities. All of the above actions need to be handled in a standardized and centralized approach in order to be effective and consumable by the different roles involving the use of the Test and Evaluation infrastructure. The actions need to be managed with a life cycle approach for both the management of the Test and Evaluation infrastructure and the activities within the Compute Center. The maintenance of resources, the roll back of configurations, and the validation testing of an environment before releasing it to the consumers are all examples of actions that are repeatable yet highly configurable and complex.

Management needs to understand how well the compute infrastructure is functioning so that decisions about the maintenance and life cycle of the T&E infrastructure can be made from the data analytics available. The infrastructure needs to have tools in place to support not only these actions, but the life cycle management of these actions as well. Most importantly, the environment needs to support new tools and processes as well as share intellectual property (IP) developed across all levels and users of the environment (administrators, developers, end users, etc.).

The Risk of Not Implementing TECaaSS

Given the financial cost of a Compute Center and its importance to the rest of the organization, it doesn't pay to make the significant capital and operational investments while neglecting the life cycle management of the infrastructure. The highly manual processes associated with life cycle management typically used in large Infrastructure labs are the enemy of reliability, repeatability, and auditability. Manual or non-managed processes are often visible in a number of ways:

- *Absence of live inventory visibility.* In most T&E environments, equipment inventory is not tracked in a way that provides live visibility to engineers. While most IT organizations perform asset tracking for financial purposes, what passes for the inventory management used by engineers is a spreadsheet that is often ill-maintained. As a result, it can be difficult to tell without exhaustive work what resources or equipment exists, is being used by whom, and what is truly available.
- *Offline topology design.* Since there is no usable inventory visibility, it follows that topology design is done completely offline without regard for resource availability. Visio or other diagramming tools are most common, and basically produce the electronic version of a paper drawing, which is usually then printed to aid in a time-consuming manual hunt for relevant equipment.
- *Chaotic connectivity management and costly errors.* Once inventory is found that is apparently available, engineers must manually re-cable connections between the equipment. With multiple engineers making adds, moves and changes, typically without up-to-date documentation, errors such as disconnecting someone else's infrastructure inevitably occur.
- *Underutilized resources wasted resources.* Often servers, memory, storage, and networking resources are locked into a particular set of virtualization tools or stacks, greatly limiting the sharing and balancing of these resources for different workloads.
- *Use of custom environments instead of COTS (Commercial Off The Shelf) tools.* Using these custom tools to manage the environment leads to excessive cost, limited use within different groups, and limited industry expertise to lower maintenance costs for the management environment. Different custom tools and environments without a common

control interface across different user roles can cause limits in adoption of the environment due to increased training and expertise needed to support multiple management environment tools and processes.
- *Lack of device/stack configuration baselining.* Engineers using the infrastructure must often change OS images, apply patches, and create new configurations on devices. Unfortunately, it's all too easy to forget to set devices or environments back to a baseline state, which means that when the next engineer uses the resource, they may wrongly assume that it is configured at a known baseline state and execute a series of test protocols on an incorrect configuration.
- *Legacy resource support.* HPC leaders must constantly be aware of obsolescence support when adopting new HPC resources to ensure compatibility and extend the life cycle of very costly resources.

The result of these manual processes is inaccuracy, inefficiency, and waste, evident through a number of indicators:
- *Lack of process integrity and repeatability.* Manual processes tend to experience operator errors that compromise process integrity. The lack of repeatability that results means that it is very hard to offer sufficient verification of processes.
- *Poor process documentation.* Manual processes are by nature difficult and time-consuming to capture in documentation for auditing purposes. When changes occur in procedures or processes, it is too easy to miss documentation steps, which can impact the audit trail.
- *Incomplete process reporting.* Process methodologies can generate voluminous results of data. Manual analysis processes struggle to digest these data and provide sufficient reporting for auditing purposes.
- *Imbalanced ratio of setup to actual usage.* Infrastructure engineers can easily spend days in the setup process for a procedure that takes less than an hour to run.
- *Very low asset utilization.* Millions of dollars in capital equipment are typically only 15% to 20% utilized. This represents a huge waste of annual capital depreciation costs and wasted capability.

There are significant implications of the inaccuracy and waste created by manual operating processes in T&E labs:
- *Risk of errors and non-optimized T&E infrastructure due to process integrity, repeatability, and documentation issues.* Even if the processes are painstakingly performed in an accurate fashion most of the time, the inefficiency and slow pace of manual or separate custom processes may make it nearly impossible for allocated personnel to achieve fast T&E infrastructure delivery, which causes a reduced utilization of the infrastructure.
- *T&E lab asset utilization under 20% represents a significant waste of capital depreciation costs.* Low asset utilization also means that as demands for infrastructure deployment grow, the pace of investment in infrastructure lab capacity will rise at a rapid rate. With large infrastructures costing anywhere from $1K to $3K per square foot inclusive of equipment costs, this can lead to huge, unnecessary CAPEX outlays over time.

TECaaSS Implementation

PCIe based Interconnect Network

Starting with a fundamentally different architecture, *PCIe interconnect network* eliminates the bottleneck. This architecture can construct a multi-rack, composable infrastructure that performs as if every storage and compute element was inside a single box, providing many benefits:
- *PCIe interconnect network* provides wider lanes and faster data throughput (256Gbps full duplex). *PCIe interconnect network* is administered using APIs (Application Programming Interface) that provides a simple interface for configuring computing clusters on-the-fly.
- *PCIe interconnect network* is 100% compliant with the industry's leading standard, PCI Express, ensuring high levels of support and compatibility from an enormous selection of vendors and technologies. Every new storage, acceleration, and compute technology fully supports the latest PCIe standards ensuring full access to the latest and most capable technologies.
- And as IT experts begin to use new architectures for moving compute to the data at the edge of your networks, *PCIe interconnect network* is a natural choice, offering the greatest depth of support in storage, compute and acceleration technology, the highest density, lowest power, and best performance.

Middleware Automation Framework for TECaaSS

Using a TECaaSS solution to manage the life cycle of a Compute Center infrastructure environments can help users achieve dramatically higher accuracy, utilization, and productivity. This will lead to significant CAPEX and OPEX savings, faster infrastructure cycle completion, and sustainably documented processes and reporting for metrics and auditing of the Compute Center Infrastructure's performance. A sound automation and provisioning solution that delivers a fully integrated, object-oriented software framework for automating development, administration, and end user operations on the Compute Center infrastructure controlling from PCIe (Layer 0) through Layer 7 orchestration and provisioning includes:

- Centralized live infrastructure and resource inventory
- Inventory-aware stack/topology design
- Shared calendar based resource and topology reservation
- Connectivity mapping and automated connectivity control
- Easy to create automated provisioning tasks
- Non-programmer friendly automation workflow creation based on a library of highly reusable, template-based objects that can be created from a wide variety of sources and leveraged to create:
    - Auto-discovery, auto base-lining, and other automated maintenance routines
    - Full test automation workflows
- Community sharable IP for automation and management of HPC infrastructures and processes
- Powerful automated reporting that provides a verifiable and sustainable audit trail
- Resource agnostic (any device, any cloud, any hypervisor) to support new technologies
- Ownership of all logs and data sets produced by the toolset

If designed properly, the TECaaSS architecture avoids the pitfalls of script-based approaches to automation, which cannot scale due to their high maintenance costs. Best of breed commercial solutions deployed by industry leading organizations worldwide provide them with the fastest path to successfully and sustainably automated framework environments. This is the path which leading power utilities, enterprises, government and military agencies, telecom service providers, and technology manufacturers have chosen to transform chaotic manually driven environments into highly efficient infrastructure operations. These organizations have the ability to perform the following:

- Manage infrastructure inventory including Servers, GPUs/Accelerators, Flash/Storage, L1/L2/L3 switches, and virtual resources such as virtual machines, virtual switches, and containers in a live, searchable database of resource objects tagged with searchable attributes. This capability eliminates manual searching for equipment in racks, and allows engineers to interface with the data center infrastructure efficiently via software. An inventory and resource management tool with object support and hierarchies can represent relatively simple nested resources such as chassis, blades, and ports, or complex, pre-integrated resources stacks such as converged infrastructure and workflow based, stack solutions
- Create variable or abstract topologies via a software GUI that allows drag and drop of resource objects onto a canvas, visually ascertain availability, design, and sanity check connectivity. Save the entire topology as a high-level object in the resource library, so that it can be reused later by other engineers.
- Schedule resources and entire topologies through a common calendaring system, preventing use case disruptions.
- Manage connectivity remotely by generating patching or cabling requests to lab administrators, or if PCIe/Layer 1 switches are in use, to automatically connect and build topologies.
- Make device and service provisioning error free by building automation objects for common provisioning tasks, and execute them from a graphical test topology view. Device/VM provisioning can include uploading OS images, resetting device configurations to baselines, or creating routing adjacencies between virtual switches.
- Create auto-discovery and auto-baselining processes that leverage an extensive array of control interfaces, GUI automation and scripting capabilities to streamline the management of inventory and device states to a compliant baseline.
- Automate complex provisioning and configuration management tasks in a fully documentable and repeatable fashion. Automation can be created through integration of existing automation scripts as objects, as well as creation of new automation objects through screen, GUI, and other capture processes.
- Support for including open source tools, APIs, and existing scripts into the environment and managing them as objects to facilitate reuse, centralization, and standardization of IP.
- Build, configure, and rapidly deploy virtual networked environments through an easy to use, multi-tenancy web portal GUI. Embed other tools to allow integrated workflow applications and other tools into a single pane of glass environment

for easy to consume interfaces for end users.
- Use compute, storage, and networking resources in an optimal and hyper-converged deployment for shared resource pools to meet on-demand needs of users.
- Support Rack Scale Design (RSD) for aggregation/disaggregation of HPC resources.

Support virtual resources from any hypervisor and any physical resource vendor, allowing for a universal user interface for all consumers of the infrastructure.
- Allow multi-tenancy in a secure virtual and physical environment to meet security compliance validation. (Encryption of passwords, Single Sign On, single file virtual network containers.)
- Generate comprehensive audit compliant result reports.
- Produce custom business intelligence dashboards to allow for managers to collect and analyze data from the testing activities and metrics for input into planning initiatives.

The TECaaSS's Beneficial Impact on the Infrastructure

Adoption and deployment of a TECaaSS methodology supporting *PCIe interconnect network* interconnect technology on your Compute Center leads to significant, positive impacts:
- ***Sustainable auditability.*** With automation comes built-in documentation of automation processes since the object-oriented method of creating, modifying, and maintaining template elements creates an ongoing and live documentation for process composition and methodology. Automated equipment maintenance processes with documented schedules provide proof of the compliance of the testing environment. Automated results analysis offers robust reporting that offer solid proof of compliance and compliance efforts. Complete control of all data sets produced by the framework allows for control and ownership of all metrics and outputs produced by the toolset.
- ***A dramatic increase in the velocity of infrastructure delivery.*** Organizations routinely report time savings upwards of 70% in their deployment cycles once they have automated the process of allocating devices, device/VM provisioning, running automation processes, and generating reports.
  - **Performance**
    - *PCIe interconnect network* delivers the industry's lowest latency AND the highest effective bandwidth. Latency from system memory of one server to system memory of any other is less than 200ns – true PCIe performance across the entire cluster. The current Gen 3 implementation delivers 256Gbits/sec bandwidth, soon to scale up to 512Gbits/sec with PCIe Gen 4.
  - **Flexibility**
    - *PCIe interconnect network* can unite an unprecedented variety of resources, connecting accelerators of all types including GPUs, TPUs, FPGAs, and SoCs to other compute elements or storage devices such as Non-Volatile Memory Express (NVMe), PCIe native storage, and other I/O resources. *PCIe interconnect network* can span multiple servers and multiple racks to scale up single-host systems and scale out multi-host systems, all unified via the *PCIe interconnect network* software.
  - **Efficiency**
    - Featuring 100% PCI-SIG compliance, the *PCIe interconnect network* switch can integrate heterogenous computing, storage, and accelerators into one symmetrical system-area cluster fabric, so you can do more with less. Patented technology strips away unnecessary conversion, software layers and overheads that add latency to legacy interconnects.
- ***Significant savings in infrastructure CAPEX and OPEX.*** Organizations deploying infrastructure automation software report increases of 50% to 200% in device utilization, leading to capital budget savings, less depreciation waste, as well as accompanying savings in space, power, and cooling costs.
  - **Open Platform, Standards-Based**
    - *PCIe interconnect network* is built on, and is 100% compliant with, the industry's most widely adopted standard, PCI Express, ensuring low risk, easy integration, and long life. Further, the *PCIe interconnect network* operating system easily integrates third-party applications with its open-source design, including the open-source Redfish® APIs to provide unprecedented integration with a range of third-party applications for fabric automation, orchestration, resource allocation, and job management.
  - **Memory-Centrix Fabric**
    - *PCIe interconnect network* is the next generation, memory-centric fabric for a changing compute world. Effortlessly connects new

memory / storage products, the multitude of new accelerators and your choice of processors either directly attached or via server configs like NVMe-oF (Non Volatile Memory Express over Fabric).

- **Driving Down Cost**
  - The result is lower Capex and Opex through less hardware, higher utilization of resources, lower power consumption, reduced power, and less cooling. Avoid overprovisioning and add just the elements you need. Maximize utilization of the footprint of your data center and contribute to your bottom line.

Conclusion

Test and Evaluation Compute Centers are under tremendous pressure to maintain a sustainable compliance regimen for continuously evolving and increasing the usage and optimization of the deployment of services and resources to their user community. Deploying a TECaaSS set of tools and services to automate the life cycle management activities of the Compute Center can dramatically increase the usage and optimization of the resources within the Compute Center, allowing entities to deliver the optimized Compute Center infrastructure faster, less expensive, and with greater performance to their user community. Using this approach to managing the infrastructure ensures that the Compute Center is reliable, efficient, repeatable, and highly auditable. Entities using a TECaaSS approach can build a sustainable platform for delivering infrastructure that leverages their users' performance and capability to ensure that their bottom lines are maximized. ❑

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A New Strategy for Funding Test and Evaluation Range Infrastructure

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The source of funding for conducting test & evaluation (T&E) at our nation's open-air ranges and ground test facilities has varied over time. From prior to the formation of the Major Range Test Facility Base (MRTFB) in 1971 until now, customers using T&E infrastructure have gone from not paying anything to having to cover the majority of cost themselves with varying degrees in between. Following the National Defense Authorization Act of 2003, customers currently are accountable for the direct costs associated with their test, and indirect costs are provided using institutional funding, with a few exceptions. Under this construct, the institutional accounts have struggled to sustain and modernize existing infrastructure and invest in new infrastructure to support the T&E capabilities required for testing future systems. This article describes an alternative funding strategy to reduce the risk of not having the T&E infrastructure in place when programs need it.

Introduction

This article addresses Major Range and Test Facility Base (MRTFB) funding as it relates to Department of Defense (DoD) customers. Some of you may recall the cartoon series "Popeye." A catchphrase used by a character named, J. Wellington "Wimpy," was "I'd gladly pay you Tuesday for a hamburger today." Zukor, A (1934). This reminds me of how we fund our T&E infrastructure following the Bob Stump National Defense Authorization Act (NDAA) for Fiscal Year 2003. This change required institutional and overhead costs of a facility or resource within the MRTFB to be fully funded through the major test and evaluation investment accounts, the Central Test and Evaluation Investment Program, and other appropriate accounts. Charges to a DoD customer for the use of these facilities or resources for testing cannot be more than the amount equal to the direct costs to support that particular customer. The MRTFBs provide the "Hamburger" upfront and then get paid for the costs to prepare and serve it after it has been eaten. There are provisions in DoD 7000.14-R, Volume 11A, Chapter 12 (2016) that allow customers to be charged for upgrade and modernization needed to support a specific customer -unique test requirement. In addition, paragraph 12404.B.1.a, states "By mutual agreement, investments in new or existing test and evaluation facilities may be funded, in whole or in part, by one or more DoD users of a MRTFB activity." However, programs are reluctant to agree to this because it increases the cost of their programs.

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Secretary of Defense Packard established the MRTFB in 1971, listing 26 facilities as MRTFBs. At that time there were a lot of inconsistencies for how T&E customers were charged for using T&E facilities (Soileau, R. L. and Swanson, P. A. (1980)). Some ranges were completely institutionally funded, and customers were not charged anything to test their systems. Other ranges charged T&E customers 100% of the cost associated with conducting their tests. A funding study in 1972, known as the Bergquist Study cited in Soileau, R. L. and Swanson, P. A. (1980), highlighted these funding inconsistencies and recommended the implementation of a uniform funding policy for the MRTFBs. So, in 1974 the uniform funding policy was defined in DoD Directive 3200.11 (1974) resulting in a major change to how T&E customers were charged to conduct testing for 18 of the MRTFBs. This change was implemented at the beginning of fiscal year 1975, which at that time was July 1st, and basically said the MRTFBs could charge their customers for direct charges associated with their tests, and the MRTFBs would be responsible for all overhead (indirect and general and accounting costs). Post-implementation studies were conducted in October of 1974 and 1976. They discovered that each Service generally implemented the new policy as intended, but inconsistencies still existed between Services and between ranges for what constituted a direct cost.

Moving forward through the 1980s and 1990s, when a program office was developing a new weapon system, they would determine the T&E resources needed to adequately test their system, identify the resources in their Test & Evaluation Master Plan (TEMP), and if the needed resources did not exist within our MRTFBs, they would budget for them within their program to ensure the capability would be available when needed to support their program milestones. The accountability was to the program for having what they needed to test. Over time, the ranges grew dependent on this program funding to provide new infrastructure, and the program offices complained about how expensive it was to test their systems. There was a lot of pressure on the program offices to lower their costs. The program offices pointed out that they should not be paying for the T&E infrastructure required to test their systems and that it should be institutionally funded by the T&E providers. So NDAA 03 placed the indirect costs to maintain, operate, upgrade, and modernize T&E infrastructure in the institutional investment accounts. The T&E customers would only have to pay for the direct cost of conducting their tests, and any cost for capability unique to their program that didn't already exist and couldn't be used by other programs.

The major issue with this funding strategy is the funding source for T&E infrastructure was disconnected from the entity responsible for delivering the weapons system. The MRTFBs now have to be the champion for securing new infrastructure funding, but they are not responsible for getting the weapon system being tested to the warfighters, which makes it difficult to create a compelling story for why they need the money. To realign the champion with the need, a new strategy for funding T&E range infrastructure is required.

Today's Funding Strategy Disconnect

With pressures on the program offices to keep their costs down, and with limited availability of funds in the institutional investment accounts, a potential gap is created between what is needed to test and what is available when it is needed. The T&E organizations are struggling to make ends meet for operating and maintaining the existing infrastructure. In their modernization accounts, they are hard pressed to make a compelling case for why they need modernization funding because the business case for why is in the program offices. If the T&E community does not get funding to modernize and add new capability that a program office needs, there is not a consequence to the T&E community. The customer will have to go somewhere else, or just wait until the T&E community is successful in getting the funds and providing the capability. The consequence is on the program office side in the form of schedule slips or added costs for the possibility of having to go outside the country to fulfill their requirement, if the capability even exists elsewhere. When we detach the need from the funding stream, we lose an effective champion to successfully fight for what is needed.

The program office could identify the requirement in their TEMP, say it is a unique capability that doesn't exist and therefore they could budget for and fund it, or mutually agree to fund some or all of the capability to ensure they have what they need to test when needed. However, there is not much incentive to do this because as our technologies evolve, the capability does not remain unique to their program. This means other programs could benefit from having that future T&E infrastructure available and therefore the T&E community should be paying for this common infrastructure under the current rules. No program manager wants to be the first one to identify a capability is needed that does not exist because then he or she may have to pay for it.

As pointed out by P. F. Piscopo, and P. Bronson, (2018), it is possible to acquire needed funding for investing in future T&E infrastructure. However, it is very time consuming and labor intensive. I was very impressed with the methodology suggested in their article, but the test centers do not have the resources, access to information, or the organic talent to dedicate to this effort. This brings us back to the disconnect of the current NDAA 03 construct for funding T&E infrastructure. The champion isn't aligned with the funding source and there are no consequences to the T&E community for not being successful in capturing the funding necessary to put the new infrastructure in place when needed. At best, MRTFBs are able to capture fractional amounts of the funding spread out across multiple years, which jeopardizes having the capability when the programs need it to prevent costly delays. These stretched out funding profiles also have the potential to add cost due to inefficiencies associated with executing the funding over an extended period of time. An example of this is currently occurring on the Eglin range. Eglin has been successful in securing partial funding to expand the effective coverage of their data collection capability for the Gulf Range. Part of this enhancement involves laying fiber optic cable through portions of the Gulf of Mexico. The ship that lays the cable charges $10M each time it deploys to lay the cable. When the funding to buy and lay the cable isn't enough in a given year to buy all the required cable at once, the task of laying the cable has to get divided between fiscal years, which results in having to pay the $10M again and again until all the cable can be laid.

Need a Compelling Story

Many years ago, I was serving as the commander of a test squadron with an aging fleet of test aircraft that were rapidly becoming unsupportable. We were having to cannibalize parts off of aircraft in museums and from aircraft on pedestals that were on static display at base entrances and in front of other buildings. I went forward with a proposal to replace these aircraft with six new ones being purchased for another purpose by adding them to the end of a production run that was being negotiated. As I told this story in the Pentagon, I was asked the question, "How many sorties have you cancelled due to not having parts?" I proudly said, "None," thinking they would be impressed with the great job we were doing by taking the extraordinary measures to procure spare parts. They quickly said, thank you very much for your time, but you do not need new aircraft you just need to keep doing the great job you are doing to keep your fleet flying.

Sometimes the test centers can be their own worst enemy when it comes to justifying needed infrastructure. Our test centers are made up of success-oriented people that go above and beyond to get the job done successfully. There are hundreds of stories of how they did amazing things to get the missions off and support the customer. So, when they go forward to make the case that we need better radars or new T&E infrastructure to support their future customers, they do not have a compelling story to tell that justifies the investment. Success is a wonderful thing, but it does not go a long way when fighting for limited dollars against investments for other failing infrastructure projects.

When fighting for limited resources, it is essential to not only tell the benefit of the investment, but more importantly, the impact of what happens if you do not get the money. Otherwise from the decision-makers' point of view, they expect you to just keep doing the great job you are doing to support your customers. You have to build your compelling case for which programs will not get supported and quantify the schedule delays and resulting cost impacts that will result. You have to articulate the impact of not being able to field the capability on-time to meet the warfighter's need. This really becomes a difficult task for our T&E community because they are separated from the need. It is like having a friend of a friend make the case for why you should do something rather than having you make the case directly to the decision-maker. The champion has to be aligned to the funding source.

Need a New Funding Strategy

We have to realign the champion with the funding source. Yes, that means if a program office needs T&E infrastructure that does not exist to support the development of their system, they need to be the one programming the funds. This really makes more sense to have the program offices making the case for what they need to prevent the negative impacts on their program. They are better equipped to make the compelling case for what is not going to happen if they do not get the money. Once their program is off and running, they cannot afford to push the pause button and delay their program while the T&E community argues for them and fails to obtain the required funds when needed.

I know you are saying, well this doesn't sound like a new funding strategy, it just sounds like we are going back to how it used to be in the 1980s and 1990s before NDAA 03. But what if we threw in a twist? When the United States sells equipment to our foreign allies through Foreign Military Sales (FMS), we recoup a portion of the development costs that we invested from the FMS customers. Why not do something similar for the investment in T&E infrastructure that is made by a program office. This would give them incentive to identify the need and program the funding to mitigate the risk of delay to their program.

For example, if a program office secures the funding needed for infrastructure that does not exist, they should be allowed to recoup their initial investment once they begin to test. This recoupment could be in the form of a lower rate for their direct costs associated with using the capability they originally funded, or depending on the size of the investment, an overall discounted rate for their direct costs of testing. This recoupment approach would require moving the investment funding forward by the required lead time to ensure the capability was available when needed, but the budgeted cost for the direct charges once testing began would be lower. The total dollars to conduct their test program would not be any higher across the full program, but they would have mitigated the cost increases to their program due to schedule slips, had the capability not been available on-time or they had to go external to our MRTFBs to accomplish the test, which would have cost more as well. Once the program office's investment was recouped, they would return to paying the normal direct costs of test that they currently pay. Other programs that may need this capability that was paid for by the first to need it would pay the normal direct costs for using that infrastructure. If the total investment was greater than what could be recouped using this approach, consideration could be given to recouping a portion of follow-on customers' direct costs to the original investor.

During the recoupment phase, there would be a slight impact to the RBA/DBA ratio for the MRTFB, but it would alleviate the test centers of having to fight for funding they have trouble justifying resulting from the champion and the funding source being misaligned as it is now. It is time to get the stakeholders together to relook at the current funding policies to ensure future programs have what they need when they need it to field their systems on-time and on-cost to the warfighter. This may be a worthwhile endeavor for ITEA to take on by forming a study panel of the stakeholders to determine the validity of this idea and/or the possibility of coming up with other ideas that would better align the champion needing the T&E capability with the funding source to make it happen. The accountability and the consequences should rest within the same organization.

Conclusion

NDAA 03 shifted the funding source for funding T&E infrastructure from the program offices needing the capability to the MRTFBs. The consequence of this change separated the accountability for securing funding from the organization with the need for that capability. Although there was a reduction in the program office's cost to test their systems, it added risk of cost increases resulting from schedule delays if the T&E capability they required was not successfully put in place by the MRTFB. This change also shifted the champion for securing new T&E infrastructure capability from the program office who needs it, to the MRTFBs who do not suffer any consequences if the funding is not provided.

To realign the funding source with the organization that needs to complete the testing, a change in strategy is needed. A shift in strategy that realigns need and funding source is possible while preserving the NDAA 03 intent to lower the program office cost of test. This new strategy leverages the concept of recoupment, which is used on FMS programs. This ensures new T&E infrastructure is available to program offices when needed without raising the overall cost of their program. Programming for new T&E infrastructure within the program office budget and allowing these upfront costs to be recouped during test execution result in an overall test cost that remains unchanged. This ultimately becomes a win-win for the program offices and the MRTFBs. Forming a panel to investigate the viability of this approach or coming up with a better idea would go a long way toward making sure our future test infrastructure is ready to meet the MRTFB customers' need when they need it. ❑

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Environmental Challenges and Range Sustainability

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The Department of Defense (DoD) ranges face a number of sustainability challenges related to performing their missions and potential impacts on their missions from these challenges. These challenges have grown from relatively straight forward environmental-related issues to encompass renewable energy development, Radio Frequency (RF) spectrum auctions, urban development, available air, and land and sea space limitations as well as environmental compliance. This article will address these challenges and best practices used by the ranges to address and mitigate the impacts.


Paul Knight

What Is Range Sustainability?

Range Sustainability is often confused with environmental compliance. Environmental compliance is a significant subset of Range Sustainability but does not encompass the totality of Range Sustainability. Range Sustainability is an overarching approach to ensure that the ranges can successfully prosecute their mission by ensuring access to ranges, facilities, and resources and that there is public support for their test, training, evaluation, and experimentation mission. Range Sustainability encompasses much more than just compliance with environmental laws and regulations. A successful Range Sustainability program needs to have a robust planning process, be proactive in anticipating requirements, engage stakeholders, and meet legal requirements in advance of mission requirements to preclude mission impacts.

What Are the Challenges?

In today's environment, there are a number of challenges that the ranges confront on a daily basis. Principal among these are potential impacts from renewable energy development and energy transmission corridors, the on-going auctioning of Federal exclusive use RF Spectrum, urban development, inadequate air, land, and sea space to support today's requirements and traditional environmental compliance. While this list is not exhaustive of all challenges, it does include those that have large potential impact to range missions and require significant effort to monitor and mitigate. Each of these challenges will be addressed in detail in subsequent paragraphs.

Discussion

Renewable Energy and Transmission Corridors

Renewable Energy projects and their associated transmission corridors present the ranges with numerous challenges as discussed below:

Wind Energy

Wind farms have the potential for impacts on ranges and range activities such as low-level aviation testing and training, ground-based radar, airborne systems, ground space, sea space, and habitat and species impacts.

Low-level Aviation Testing and Training Impacts

a. Turbines associated with wind farms create obstacle avoidance areas and may require units to abandon the lower altitudes of military training routes (MTRs) and special use airspace (SUA). Turbine heights can reach well over 400 feet above ground level (AGL) and wind farms can cover thousands of acres of land, requiring pilots to traverse the farm above the lower limits of the airspace.
b. Wind turbines impact airborne radar by causing false returns (via Doppler shift), which could be an impact during training missions.
c. This Doppler affect causes significant concerns for the DoD test community, as validating airborne radar systems in a cluttered environment is virtually impossible. Siting is a critical component in securing clutter-free airborne radar test areas.
d. Wind turbines can affect weapons and communications systems prone to electromagnetic interference.
e. Large farms could impact helicopter low-level terrain following routes and other non-published training airspace. Loss of the lower altitudes over

thousands of acres may require aircraft to transition at a higher altitude, impacting low-level training.

f. The larger farms with taller turbines can impact low-level night vision training.

Ground-based Radars Impacts

Wind turbines impact ground-based radar systems in three ways:

a. The large radar cross-section of the reflections from windmills significantly increase the noise floor and can cause radar receivers to be driven into saturation. Also, other processing functions can exhibit nonlinear behavior. These effects reduce, or even eliminate, the ability of the radar to detect targets near and within the wind farm area and negatively impact test and training.

b. The second characteristic of wind farm interference with radar performance is the Doppler shift caused by the turning blades. The velocity of the windmill turbine blade is dependent on the distance from the center of the turbine hub, with an increasing shift moving from the center to the tip of the blades. Thus, the rotating blades produce a continuous spectrum of frequency shift with much of the spectrum falling within the Doppler limits that air surveillance radars are optimized to detect.

c. Wind turbines are capable of causing range tracking instrumentation to lose lock on airborne test items by providing a larger, more attractive target than the test item. This could have catastrophic consequences on test integrity and safety. In most cases, wind turbines must be in the line of sight of a radar to impact it. However, there are situations in which turbines can cause problems even if they are out of line of sight. Instrumentation radars and radar cross section measurement systems may be particularly prone to interference. Mitigating measures, such as receiver modifications or limiting coverage areas, can degrade test and training capabilities.

Airborne Systems Impacts

Wind turbines have the same types of impacts on airborne radars as they do for ground-based systems. However, these issues are amplified by the fact the airborne radars are at some altitude above the ground, increasing their line-of-sight radar horizon and minimizing any masking of the turbines by terrain features.

Ground Space Impacts

Large wind farms on Bureau of Land Management (BLM) lands used by the DoD to meet training requirements can impact ground maneuvers. The loss of this land will require the units to locate new maneuver space suitable to meet training requirements. Use of new lands will require environmental documentation in support of the training.

Sea Space Impacts

In addition to the impacts previously described, wind turbines could impact sea lanes, submarine transit lanes, coastal test and training ranges, and may even induce background noise into the surrounding sea area and compromise sonar test and training.

Habitat and Species Impacts

Wind projects whether on non-DoD lands or on DoD lands can result in direct mortality to birds and bats, can lead to avoidance behavior in ground-nesting birds such as sage grouse, can fragment habitat and disrupt seasonal migration patterns, and can directly destroy occupied or unoccupied habitat for species. Such impacts on listed, candidate, or otherwise sensitive species or habitat (whether or not occupied by the species concerned) also found on DoD lands can have significant second-tier effects on DoD by increasing over time Endangered Species Act related restrictions on DoD operations, especially ground operations.

Solar Energy

Solar farms can have multiple impacts on test and training. Some of these are the following:

a. Solar thermal plants can have a very high thermal signature and may interfere with infrared (IR) sensors. These IR sensors can actually lock onto the solar plant. These factors should be considered in/around ranges that use IR technologies.

b. The type of solar used can impact Special Use Airspace (SUA), Military Training Routes (MTRs), and areas utilized by the military for ground maneuverability training.

c. Large solar farms using panels can reduce available ground training space.

d. Solar projects using towers can reach heights of more than 800 feet AGL. This type can impact all types of airspace and aviation test and training missions. The Federal Aviation Administration does require that all structures above 199 feet AGL be sent through the Obstruction Evaluation/Airport Airspace Analysis office for determinations of impacts to aviation.

e. Solar energy facilities sometimes utilize wireless control systems that can interfere with or be interfered with by DoD systems.

f. Solar facilities may cause reflectivity from the sun. This phenomenon is known as glint (instantaneous flash) and glare (continuous blinding) and can be quite severe depending on the type of facility and angle from the sun/exposure time. Glint/glare from nearby solar facilities should be considered from a safety of flight and eye exposure perspective on DoD ranges.
g. Solar thermal plants can consume large amounts of water, which could impact an installation's and the region's water supply both in terms of quality and quantity. Especially in arid regions, this impact on water supplies, and especially on groundwater, can, in turn, have severe impacts on species, which can result in second tier impacts through additional restrictions on DoD water usage for other purposes and on increased restrictions on DoD operations under the Endangered Species Act (ESA). In the desert Southwest, the impacts of climate change are expected to significantly decrease water supplies in the future, making impacts on water increasingly significant.
h. Solar plants involve the destruction of habitat, requiring both terrain leveling and eradication of vegetation with periodic retreatment with herbicides. If such impacts are not minimized through careful siting, and if sufficient mitigation (whether or not required by existing provisions of law) isn't provided, installations could be put under more ESA or Clean Waters Act (CWA) restrictions with resultant constraints on mission capability.

Transmission Lines

Nearly all renewable energy plants require new transmission lines. Since renewable energy sources are often distant from load centers, long haul transmission lines are being planned to facilitate the construction of renewable energy plants. Transmission lines can have mission impacts such as those described below:

a. Transmission lines and towers can impact SUAs, MTRs, and other low-level aviation missions.
b. Transmission lines emit electromagnetic energy that can impact range systems, especially where electronic warfare testing or training is conducted.
c. Fragmentation of habitat and disruption of migratory patterns as well as other adverse impacts on species and habitat can occur. These can result in additional pressures and restrictions on the activities that DoD can engage in.
d. Proposed use of electrical transmission lines for broadband wireless may cause additional impacts.

RF Spectrum Auctions

At a time when DoD needs for spectrum to support operations, training and test and evaluation activities are growing exponentially, the access to dedicated spectrum is rapidly diminishing. Higher resolution radar, networked telemetry, streaming video/persistent Intelligence Surveillance Reconnaissance (ISR), agile data links and radios and ever more complex electronic warfare are but a few of the systems and capabilities driving this need. After losing a significant portion of the aeronautical telemetry band (lower L Band), there was a hope among the ranges that this would be a one-time event and life would continue as usual. The successful sale of 65 MHz of spectrum during the AWS-3 auction (1695-1710 MHz, 1755-1780 MHz, 2155-2180 MHz) that generated more than $40B coupled with ever-increasing consumer demand for wireless capabilities seems to have only increased the appetite for selling yet more Federal Spectrum. There are currently numerous bands between 400 MHz and 8 GHz being reviewed for auction in the near future. Responding to data calls, defending and advocating for Federal use of spectrum is a full-time requirement and a drain on range resources. Given the numerous commands, activities, and the thousands of systems owned by DoD, providing consistent and coordinated responses across the breadth of DoD to the numerous data calls and spectrum auction proposals is a continuous challenge.

Urban Development

With the continued growth and expansion of Urban areas, DoD facilities that were once isolated and "in the middle of nowhere" are now adjacent to or in some cases surrounded by major population centers. This can lead to increased complaints about aircraft noise, vehicle noise, hours of operation, explosions, etc. There are numerous examples of development literally up to the fence line of DoD installations. This makes it increasingly difficult and expensive to conduct the facilities primary mission while also being a "good neighbor". The encroachment of urban development onto wildlife habitat can result in the migration of threatened and endangered species onto DoD lands and subsequent additional requirements, restrictions, and costs for DoD activities.

Air, Land, and Sea Space Limitations and Concerns

Most of the major test and training ranges were created in the period immediately prior to, during, or shortly after the Second World War. Their boundaries have remained largely static since their creation. While more than adequate for the testing and training with the weapons of the 1940s and 1950s, they are inadequate to contain the long range, directed energy and hypersonic weapons of today. Given the difficulty in acquiring more land, air, and sea space to expand ranges, the interlinking of existing ranges is being explored. Interlinking existing ranges brings with it its own set of safety, environmental, operational, and technical challenges.

The increasing use of technology by the general public and competition for sea space represent growing issues for sea-based ranges. Deployment of Unmanned Underwater Vehicles (UUVs), hydrophones, and acoustic Doppler profilers are more prolific as technology costs decrease and ocean exploration increases. These technologies can directly interfere with range activities and or inadvertently capture sensitive or classified information. There are currently no mechanisms to require notification of the Navy for deployment of these types of systems in Ranges or transit routes.

Additionally, the use of aerial drones and sensors by the public and commercial sectors presents a similar set of concerns for safety, interference with range missions, and data security for the open-air ranges.

Environmental Compliance

Environmental compliance requires monitoring and compliance with a number of Federal Laws such as the National Environmental Policy Act (NEPA), Marine Mammal Protection Act (MMPA), Native American Graves Protection and Repatriation Act (NAGPRA), Clean Air Act (CAA), Clean Waters Act (CWA), Endangered Species Act (ESA), Migratory Bird Treaty Act (MBTA), et al. In addition to these federal requirements, there are state and local laws and regulations that individual ranges must be cognizant of and compliant with as well. While most of these requirements are well understood, the resources required (labor and funding) to stay on top of them continue to grow. The required coordination and consultation can entail significant lead time (years) for some projects to get to the approval stage. In some cases, the required mitigations can impinge on the ability to execute the mission. Restrictions on areas of tracked vehicle use, limitations on the number of ground troops, prohibitions on area use during certain times of the year are a few examples of these restrictions.

Best Practices for Range Sustainment

While each facility and range will have unique issues that require tailored responses, there are some cross cutting techniques and universal practices that all can benefit from:

a. Foremost, have a dedicated office with full-time staff with expertise and ability to provide continuous outreach and coordination with agencies and stakeholders external to the facility or range. The sustainability staff should have the ability to reach out to Subject Matter Experts (SMEs) to augment their knowledge. They can't be experts in every technical discipline.
b. Perform continuous outreach. Provide constant and consistent communication with regulators, local communities, and other stakeholders.
c. Be proactive and get out in front of issues. Plan ahead and anticipate how stakeholders will react and have your responses to their concerns at hand. This is particularly important given the lead times some actions take. Take into account the lead time involved with securing environmental approvals such as Environmental Assessments (EA) and Environmental Impact Statements (EIS) and plan accordingly.
d. Communication and Outreach should not just be local but at the state and regional level as well. Continuous outreach and early participation in land use planning processes and energy siting criteria are key to successful engagement and mission impact mitigation.
e. Coordinate with other DoD and Federal activities both locally, at the state level, and regionally as well. Have a consistent unified DoD position on whatever the issue might be. Remember that other agencies like BLM and National Park Service (NPS) as well as state agencies are stakeholders too. Establishing close relationships with land use decision-making agencies and maintaining an educational and outreach drumbeat with them to ensure DoD concerns are captured and carried forward into planning documents and decisions are essential.
f. Educate, early and often. As part of outreach; educate the public, governmental bodies, regulators, and non-governmental stakeholders about your mission and its importance to support our warfighters and national defense. As players will change over time, this educational process needs to be continuous and ongoing.
g. Be as transparent as possible. Understanding that security issues may sometimes limit what can be said about a particular action, whenever possible be transparent. This helps with establishing credibility and trust.

h. Take advantage of programs and partnerships like the DoD Readiness and Environmental Protection Integration (REPI) program that establishes buffer zones and easements to protect military missions from encroachment.
i. Time, effort, and resources applied early will save the same over the course of a project. It is more efficient to apply those resources up front rather than try to make it up retroactively.

Conclusion

While the challenges faced by the ranges today are many, varied and complex, given a dedicated staff of professional sustainability personnel, proactive engagement, and long-term commitment, mission impacts can be avoided or at least minimized. Done properly, Range Sustainability is not cheap but the alternatives are far more expensive in the long run and can result in major mission impacts to our warfighters. ❑

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StreamServer for Fast Data Analytics

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A class of efficient processing methods known as Streaming Analytics is emerging within Distributed Systems to analyze the contents of high velocity, high volume data streams in real time. Streaming Analytics can potentially solve a variety of computationally hard problems. However, realizing these solutions depends on the ability to feed high-throughput test streams into analytics systems under development. This article describes an exploratory effort to address this need by developing a tool called "StreamServer." The StreamServer team started by rehosting capabilities from SimServer, an existing web-based streaming tool, in a streamlined software architecture. This new application supported up to 25 times greater data throughput than the original SimServer. The proposed architecture integrated this application with Apache Kafka, a popular open source distributed messaging framework. The resulting StreamServer is a high-performance stream generator well suited to replicate and replay real world data streams for developing and testing Streaming Analytics systems.

Keywords: Streaming Analytics, Fast Data Analytics, Simulated Data Streams, Data Throughput

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1 Introduction

Operations Analysts across many domains are becoming aware of the growing number of data streams that can be mined for operational advantage. This awareness has given rise to a new discipline: Streaming Analytics, also known as "Fast Data" Analytics (Zhoe 2016). While Big Data attempts to harness the growing volume of data (Fox 2013, Walker 2014), Fast Data Analytics instead focuses on handling the velocity (Zikopoulos and Eaton 2011) and veracity (Kepner et al. 2014) of data. While handling high-volume data is of course important, it is often these other aspects of big data which can be more important to consider when designing an adaptive streaming capability.

Example use cases for Streaming Analytics include (not a complete list):

- Monitoring the health and status of equipment, whether networked computers or manufacturing machinery
- Distilling social media sources to detect alarming behaviors or opportunities to influence
- Discovering patterns or anomalies in vehicle traffic
- Sifting through web clickstreams for in-the-moment e-commerce opportunities
- Examining sensor feeds for patterns that require immediate attention due to safety concerns (health care, weather, air traffic) or defense (cyber, military) considerations

Developing tools to meet big data streaming requirements can have profound impact on real world deployments. For instance, The MITRE Corporation explores technology solutions for government agencies and military services, many of whom are curious how Streaming Analytics can be leveraged to improve their operations. Tapping into live streams of data suitable for feeding these experimental algorithms is typically not possible, due to data sensitivity and network isolation issues. What's needed is a way to generate realistic data streams in the lab environment to test and demonstrate the algorithms.

This manuscript chronicles the efforts involved in prototyping a high-performance stream generator which addresses these big data processing needs. Initially, an existing MITRE internal "SimServer" web-based data replay service was leveraged as a starting point (Flournoy et al. 2005). Though SimServer was sufficient to support many interface testing and demonstration customers with low-to-medium volume and velocity data streaming requirements, it quickly became obvious that a stream generator with much higher throughput would be necessary to support Streaming Analytics development. In order to address this issue, several of SimServer's core features were utilized from the web-based software architecture and hosted in a streamlined, high-performance architecture. This formed the basis for the current iteration of StreamServer. StreamServer was then mated to Kafka (Kreps et al. 2011), a popular open-source message streaming framework being adopted by many of the MITRE Streaming Analytics research efforts.

The data sets used in a throughput testing capacity for this effort represented two high volume and velocity sensor feed use cases. The first test case included alerts, health data, and events from network sensors in a notional cyber monitoring scenario. The other test case contained periodic location updates for numerous aircraft in a busy regional air traffic scenario.

The rest of this paper is organized as follows: In Section 2, background information is provided on the preexisting SimServer and Kafka capabilities. Section 3 briefly presents the limitations of previous implementations of these technologies. Based on these experiences, Section 4 summarizes the proposed solution that led to this effort. Section 5 details how the project team implemented the solution in use case context. Section 6 provides performance results from trials with the prototyped implementations. Finally, lessons learned and potential next steps are summarized in Section 7.

2 Foundational Technologies

Two capabilities that provided a foundation for the StreamServer effort were:

- the SimServer data replay website
- Apache Kafka, a popular open-source data streaming framework

2.1 SimServer

The MITRE corporate resource SimServer is a highly configurable, self-service data replay website that provides time-streamed scenario data for test, demonstration, and experimentation (Flournoy et al. 2005). Over the past several years, SimServer has served data to many projects and users on the MITRE internal network in addition to deployment in isolated research enclaves and military labs.

SimServer operations are based on the data pipelining concept illustrated in Figure 1. Users create a data stream "configuration" by choosing from a wide variety of data source scenarios (illustrated by the yellow data cylinders), selecting and tailoring simple data transformers (blue arrows) to modify data fields or filter out data records, and assigning emitters (red lightning bolts) to direct the stream to one or more destinations on the network.

In order to understand this configuration concept more clearly, it is useful to walk through the sample configuration shown above. Here a SimServer user has created a data stream configuration representing the location of vehicles over time during a notional amphibious vehicle attack on Kuwait by sea. For a data source, he finds a SimServer Boston attack scenario that fits his basic needs for vehicle types and routing. By adding SimServer transformers to this Boston-based scenario, he relocates the scenario to the Kuwait area,

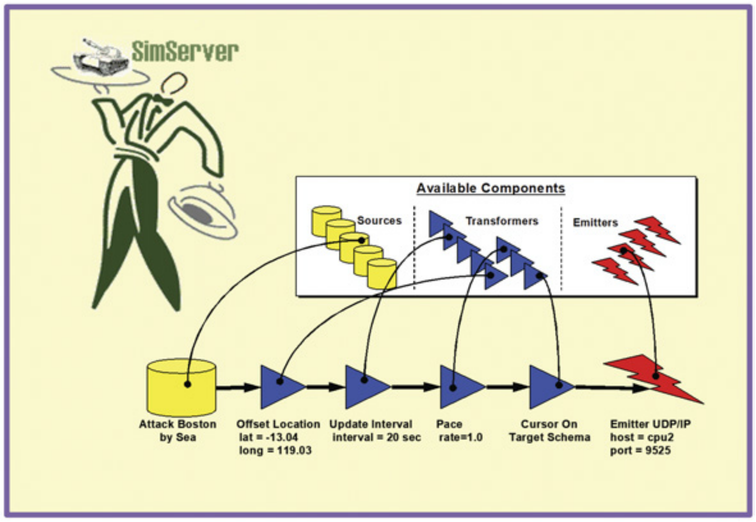


Figure 1: SimServer Data Stream Configuration Concept

specifies that platform locations be updated every 20 seconds, synchronizes the activity to wall clock time by setting the pace to 1.0, and transforms the data to the desired eXtensible Markup Language (XML) format. Finally, a SimServer emitter is added that directs the data stream to the appropriate destination computer and port. Once configured, the user can execute this custom data stream, then monitor the progress of it and other streams from the site's Monitor page (as shown in Figure 2). From the Monitor page, the user can also control the flow of a data stream by pausing or resuming the stream or changing the clock rate (pace) during execution.

The Pace Transformer is the key to SimServer's ability to recreate realistic temporal spacing between time-stamped data records as it streams them. As each record reaches the Pace Transformer, its timestamp is compared to the timestamp of the previous record and delayed accordingly. If the data records were created by logging a real-world data stream, a SimServer user can recreate the temporal spacing of the original real-world stream by setting the Pace rate to a value of 1.0. Or, if the SimServer user wants to test the processing throughput limits of an application by increasing the data velocity, they can raise the rate and stream the data at many times the original speed. This pacing capability, coupled with SimServer's pause and resume functions, provides a high degree of temporal control useful for testing and demonstration of stream processing software.

2.2 Apache Kafka

Apache Kafka is an open source, distributed streaming platform that is gaining popularity as a publish and subscribe messaging system for stream analytics (Apache 2017). Kafka's cluster-friendly design promotes very high data throughput and reliability. Because many of MITRE's Streaming Analytics research projects were migrating their efforts to Kafka, the StreamServer team investigated how to generate streams that could feed into a Kafka framework to serve these projects.

At its core, Kafka manages the flow of data records (i.e., messages) organized in categories called topics. Figure 3 provides a basic illustration how application clients connect to Kafka to exchange and process data. Basically, Producers publish records to the Kafka topics, where they are delivered to subscribing Consumers.

A Stream Processor is a special type of Kafka client that both subscribes and publishes to topics. In the field of Streaming Analytics, Stream Processors contain the algorithms that distill (filter, match patterns, etc.) the incoming data to notify consumers of interesting, or perhaps alarming, cases for further action.

The StreamServer team noted that the Stream Processors and Consumers were the focus of many of MITRE's Streaming Analytics research projects, and that StreamServer could "play" in the Kafka framework as a special type of Producer that re-streams logged data records with timing and control capabilities invaluable for testing and demonstration purposes.

2.2.1 Analysis in Motion (AIM) Project

Surveying existing Kafka projects, the team didn't find many projects using data replayers with SimServer's temporal control capabilities (as described at the end of Section 2.1). However, they did find one

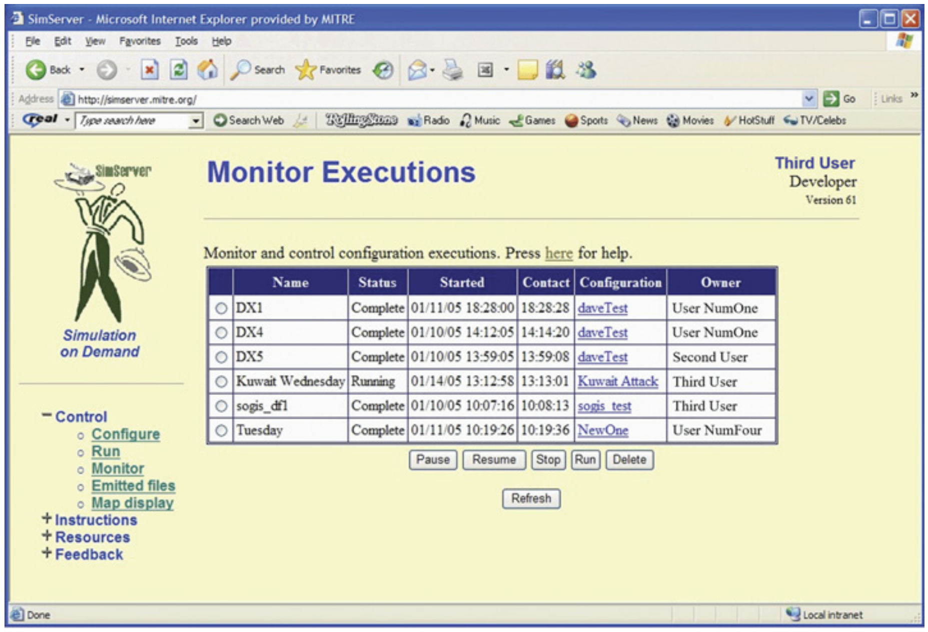


Figure 2: Monitoring and Controlling Streams from the SimServer Website

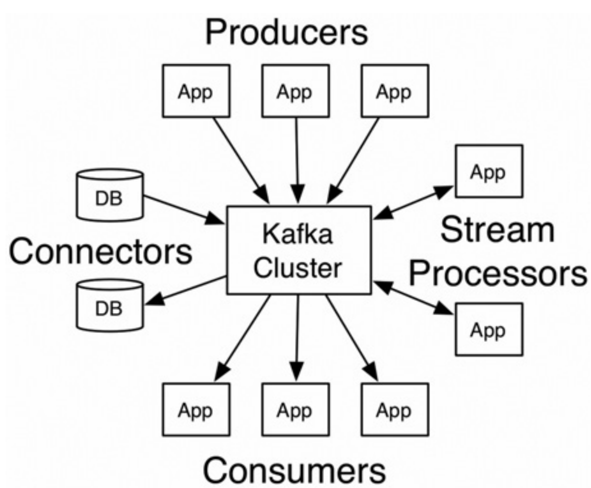


Figure 3: Kafka Client Operations Concept (Apache 2017)

such project that gave them confidence it could be done effectively: the AIM project at the Pacific Northwest National Laboratory (PNNL) (Kleese van Dam et al. 2015). PNNL had a requirement for a high-performance cloud framework they could use as both a developmental testbed and production analysis environment for interfacing their analysts' stream processing algorithms. The basic structure of the resulting AIM environment is shown in Figure 4. The AIM project has had notable successes using this environment for Streaming Analytics work in support of customers from a variety of domains including medical, energy, and other government sponsors.

3 Limitations of Existing Technologies

3.1 Pros

Over the course of several years supporting projects with SimServer, projects appreciated being able to go to an always-available service to initiate their test streams on demand, rather than having to build and maintain their own data replay software. They also liked the way SimServer used the timestamps in their data scenarios to insert realistic temporal spacing between streamed data records, and StreamServer's built-in capability to pause and resume streams and adjust the clock rate of streams for demonstration and testing purposes.

3.2 Cons

However, SimServer's web server and XML-centric architecture introduced performance limitations, so projects that had high data volume and/or high velocity streaming requirements often bumped up against these limitations. Interestingly, the "public" website access and stream configurability features enabled by this architecture were not as useful to the projects as anticipated. Projects often wanted their own copy of the SimServer system for privacy reasons due to data sensitivities. Further, they didn't make much use of the configurability afforded by the XML-based pipelining structure—once they designed a stream configuration that worked for them, they rarely changed it. These experiences supporting projects with the original

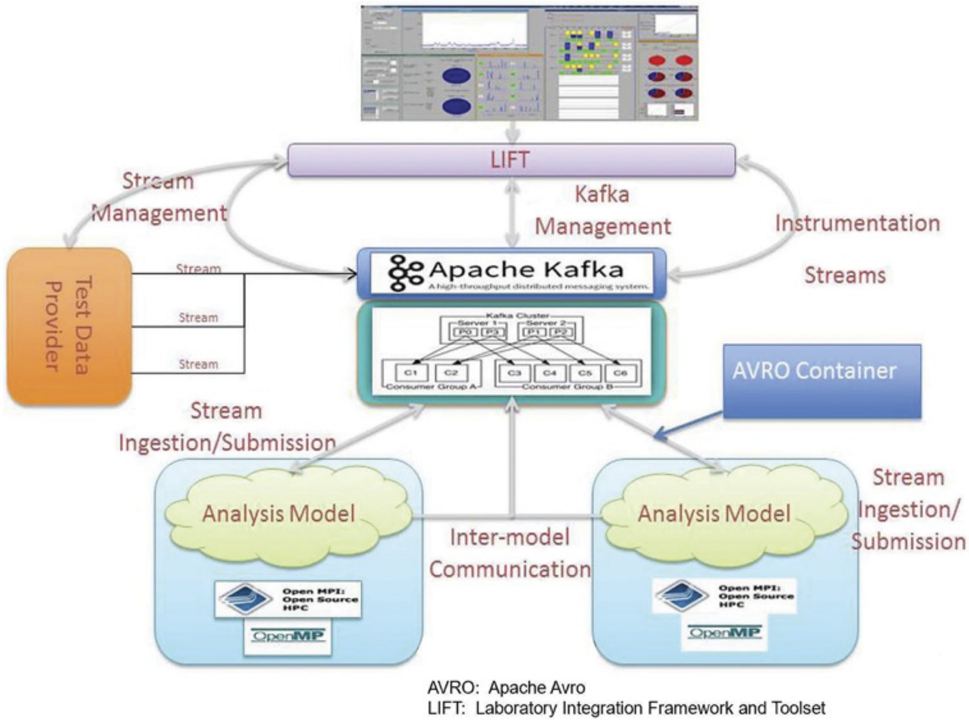


Figure 4: AIM Phase 1 Streaming Analytics Environment (Kleese van Dam et al. 2015)

SimServer, coupled with discussions with the AIM team where they too revealed having occasional issues with their own web-based stream control interface, led the StreamServer team to depart from the web interface and consider a more streamlined software architecture. This architecture will be discussed in Section 4.

4 Proposed Solution

This section provides descriptions of, and rationale for, design choices associated with the StreamServer team's prototyping efforts. The work was performed in two stages: (1) rehosting selected SimServer capabilities in a streamlined application (StreamServer), and (2) integrating StreamServer into a Kafka stream processing framework. These two stages are addressed below.

4.1 Simplifying SimServer

The goals for rehosting key SimServer features in a more streamlined software architecture were to (1) increase data throughput and (2) improve Graphical User Interface (GUI) reliability and response time associated with stream control actions.

To meet these goals, the team's first design change was to move away from SimServer's web-based architecture and, instead, build StreamServer as a Java/Swing application. The primary benefit of the web architecture—that is, the ability to have a centralized public service accessible by all user projects at all times—was not something SimServer users valued much in actual practice. In fact, most SimServer users were wary of having their data sources posted on a central server, and some even requested a private copy of SimServer they could host themselves in a standalone laboratory.

The original SimServer used an integrated Apache/Tomcat web server approach with static web screen functionality hosted in an Apache server and dynamic control functions coded into a Java Tomcat webapp. The communications required between the two web servers proved cumbersome, resulting in throughput limitations, slight GUI response delays, and occasional dropped control requests. Migrating to a multi-threaded Java/Swing application with a separate GUI thread immediately solved the GUI response time issues and eliminated the dropped control requests.

The team's second design change was to remove the XML pipeline software layer from the stream thread code. The effect of this change was to sacrifice some of the stream configurability afforded by the transformers illustrated back in Figure 1, in hopes of gaining a leap in stream throughput. The geospatial and reformatting data transformer options available in the original SimServer, such as the "Offset Location" and "Cursor on Target Schema" transformers shown in Figure 1, were abandoned as a result of this change. However, experience with SimServer customers showed that they rarely worked with these transformers anyway. The most popular SimServer transformer was the "Pace" (clock rate control) transformer, which was cumbersome for users to change during stream execution in the original SimServer implementation. So for StreamServer, the team incorporated the pace functionality as a GUI feature and, in addition, added a time slider and date/time selectors for additional temporal control.

4.2 Integrating StreamServer with Kafka

Anticipating many StreamServer users would be streaming analytics developers working within Kafka or a similar stream processing framework, the team set to work reviewing Kafka documentation, working through hands-on Kafka tutorials, and studying the Kafka-centric approach used by PNNL's AIM team. A straightforward integration approach was designed that featured StreamServer as a Kafka Producer, Kafka Topics for each of the stream data types, and instrumented Kafka Consumers listening to each of the Topics. Additional implementation detail is illustrated in use case context in Section 5.

5 Application To Use Case

This section illustrates the products of the team's prototyping efforts and describes the use cases selected for testing the prototypes. First, the StreamServer application is illustrated, then integration with Kafka is described.

The redesigned stream management GUI for the StreamServer application is shown in Figure 5. The user selects data types to stream with the checkboxes to the left and can browse to select from different files containing each type of data. The timing bounds at the lower left and right of the screen are automatically populated based on the contents of the stream data selected; the user can edit these start and end times if desired. The user hits the play button to execute the stream, and the double-arrow to change the pace of the stream (displayed numerically in multiples of real-time, based on the timestamps in the data). During stream execution, the user can pause and resume the data and change the pace as desired.

The four stream types included in this version of StreamServer were chosen with application development and testing in mind. The top three are cyber-related data sources representing notional alerts, health data, and events from network sensors. The fourth data source is a notional air traffic scenario containing aircraft locations over time.

The Network Alerts and Air Traffic streams represented two different high velocity, high volume cases suitable for performance testing. The Network Alerts data presented a spasmodic flow challenge, containing more than 40,000 data records generated in batches over a 7-minute time period. The Air Traffic data represented a more consistent heavy flow challenge, containing about 15,000 records spread evenly over 21 minutes. The StreamServer team was able to use the streaming tools' temporal features to "crank up" the pace of the streams, further increasing throughput for testing purposes.

After completing development and testing of the StreamServer application, the team configured an instance of Kafka to handle StreamServer output according to the integration approach illustrated in Figure 6.

A single Kafka topic was created for each of the four StreamServer data types. Then the destination of each of the StreamServer streams was adjusted to flow directly into these topics during execution. On the back end of each of the topics, separate listener applications were configured to receive the data. For the purposes of this exploratory project, we did not make use of Kafka's rich clustering support; that is, we simply ran the entire Kafka setup and all four listeners on a single midgrade virtual machine (VM).

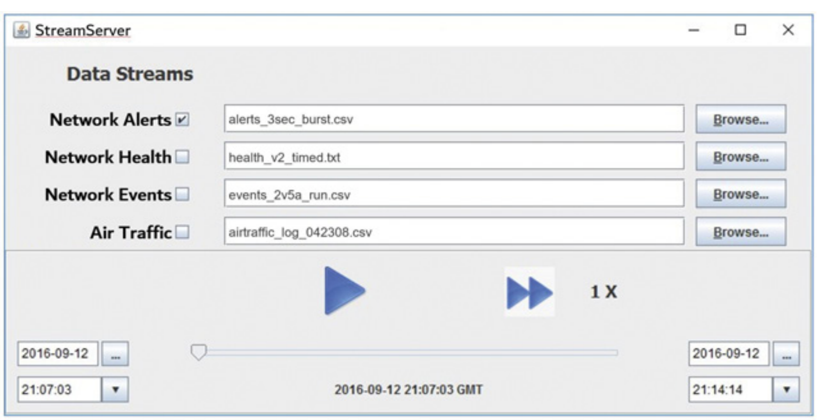


Figure 5: StreamServer Monitor and Control Screen

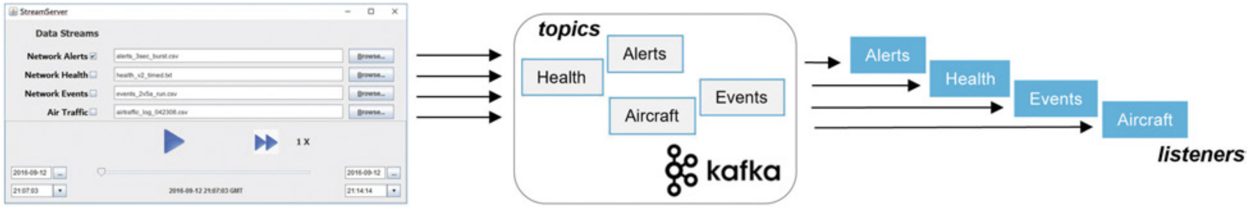


Figure 6: StreamServer as a Kafka Producer

6 Performance Results

This section presents StreamServer throughput results from instrumented testing with the sample data sets. Then, observed throughput from trials with the Kafka framework is discussed.

6.1 StreamServer Test Results

Figure 7, below, presents the throughput testing results using these data sources. Separate results tables are shown for the Network Alerts data (left) and Air Traffic data (right). The four rows of numeric results represent ever-increasing stream clock rates based on the timestamps in the data records, from real time (1x) to 8 times real time and 128 times real time, to unconstrained by time (max). The columns in each table represent (1) a perfect, zero-delay test result based on the timestamp range of the actual data divided by the pacing factor, (2) the time it took for SimServer to stream the data over a network connection to a listening app, and (3) the time required for StreamServer to stream the data over the same connection. The team made no effort to isolate network delays, as the streaming was performed between two virtual machines (VMs) on the same local cluster.

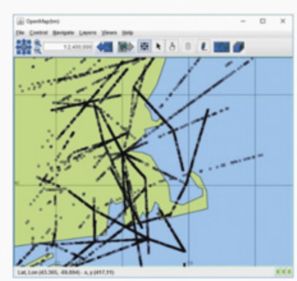
The results show a marked improvement in performance for StreamServer over SimServer for both data sources, even at the slowest (real time) tested clock rate. While SimServer incurred delays on the order of 1 – 5 minutes depending on the test performed, StreamServer finished each test within single-digit seconds of the timestamp range goal. Examining the most stressing test cases (128x and max), StreamServer exhibited approximately a tenfold increase in throughput for the Air Traffic stream and 25 times the throughput for the Network Alerts stream.

In addition to the throughput improvements, StreamServer provided instantaneous response to all user control requests through the Swing GUI (play, stop, pause, resume, clock rate change). SimServer, on the other hand, exhibited slight noticeable control delays through its web-based user interface. In all respects, StreamServer proved much more capable than SimServer of handling the high-velocity, high-volume data streaming that can be required for Streaming Analytics work.

- **Network Alerts**
  - 41580 alerts
  - 7 min 11 sec duration

Clock Speed	Timestamp Range (sec)	Web-based SimServer	Java/Swing StreamServer
1x	431	741	441
8x	53.9	335	58
128x	3.4	233	8
max	0	155	6

- **Aircraft Location Records**
  - 14765 updates (139 aircraft)
  - 21 min 6 sec duration



Clock Speed	Timestamp Range (sec)	Web-based SimServer	Java/Swing StreamServer
1x	1266	1394	1271
8x	158.3	255	161
128x	9.9	95	~12
max	0	48	~4

Figure 7: Throughput Test Results for SimServer and StreamServer

6.2 Performance Observations from Kafka Trials

The team made several runs streaming the Network Alerts and Air Traffic data sources from StreamServer, through the Kafka topics, and into the listeners. End-to-end performance approaching that of StreamServer was expected, but with perhaps a slight increase in latency due to the additional serial processing steps of loading the data into Kafka and, in turn, passing it on to the listeners. However, observed throughput performance was quite a bit less than StreamServer (though still somewhat better than the original SimServer).

Of course, this performance was observed running all Kafka topics and listeners on a single midgrade VM. Significantly better throughput might be realized by adding several higher-end VMs to this test environment and distributing the processing load using Kafka's clustering and data partitioning capabilities.

Once the StreamServer data were executed and loaded into the Kafka topics, they could be released at a later time to flow directly from the Kafka topics into the listeners. Interestingly, when the pre-loaded topic data were streamed from the back-end of Kafka in this manner, they arrived at the listeners almost instantaneously. Even the high-volume Network Alerts and Air Traffic data emptied into the listeners in just a few seconds. This result suggests the possibility that pre-loading the data into Kafka and controlling stream execution and timing somehow from "within" Kafka (or from the back-end consumer side of Kafka) could result in a very high-performance Kafka implementation. One way to accomplish this might be to simply recode the input side of StreamServer to request and process data from the Kafka topics rather than reading the data from files. In terms of the Kafka concepts shown back in Figure 3, StreamServer in this arrangement would serve as a Stream Processor rather than a Producer.

7 Conclusions and Path Forward

Our goal with this StreamServer project was to provide a SimServer-like stream delivery system tailored to meet the performance and interfacing requirements of our organization's Streaming Analytics research projects. We were able to achieve a leap in performance by making several simplifications to the SimServer software architecture as we built StreamServer. By coding StreamServer as a standalone application rather than a web-based system, and removing unnecessary stream reconfiguration functionality, we were able to achieve up to 25 times better streaming throughput. Realizing that many of our Streaming Analytics customers were developing their algorithms to run in Kafka or other similar bus-like data exchange frameworks, we explored how we could output StreamServer's data streams to Kafka topics. We found Kafka to be very straightforward to learn and interface with, and we were able to quickly develop Kafka "producer" components to receive StreamServer data streams and place the data on Kafka topics for Kafka listener components. Using this configuration and running all the Kafka components on a midgrade Virtual Machine, we ran some performance tests expecting there to be some latency due to the extra Kafka processing steps. Indeed, this Kafka setup was significantly slower than the StreamServer app running by itself (yet still somewhat faster than the web-based SimServer system).

Going forward, we believe there are two ways throughput through our Kafka-based framework can be improved. We could explore taking advantage of Kafka's clustering and data partitioning capabilities to distribute processing over additional VMs each with multiple CPUs. But even in our hardware-limited configuration, we noticed that if we pre-loaded the stream data to the Kafka topics and controlled the release of the data from the listener end of Kafka, our highest volume and velocity sample streams unloaded into the listeners instantaneously. It may be possible to achieve another leap in throughput by controlling the streaming of the pre-loaded data from the back end of the Kafka framework rather than controlling (and reloading into Kafka each time) from the front end. ❑

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Can Agile, SE, and Independent T&E Coexist and Cooperate?

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Most of the capability of complex systems is now being delivered by software, and in the process, systems engineering is getting a bad rap. We often hear that systems engineering processes are cumbersome, overly rigid and inflexible, resource excessive, and time consuming. We also hear that systems engineering is yesterday's process, replaced now by Agile, especially for software development, but hardware development as well. The bottom-line up front of this article is the following: Systems engineering is simply an articulation and structuring of logical human approach to a development. Agile brings appropriately structured methodologies to software development while maintaining the flexibility and efficiency that is needed in the world of software development. However, Agile does not make systems engineering obsolete. In fact, systems engineering actually provides a top-level structure and process to integrate Agile into large scale developments, especially of hardware/software integrated systems. Also, many elements of systems engineering are part of the processes that every Agile development team uses during each sprint.

Systems engineering is a process of understanding the user or customer needs, articulating them as requirements, defining the functions to meet the requirements, partitioning a solution into manageable pieces, allocating the functions to these pieces, developing and testing the pieces, integrating the pieces and testing each step of the way until the total solution is deliverable to the user or customer. At a top level, this also describes the Agile process. There is nothing in systems engineering that makes development take years instead of the months or weeks that Agile takes, nor that dictates that requirements cannot be refined or changed as the process evolves. There is also nothing in the Agile process that dictates that independent test and evaluation (T&E) cannot be seamlessly incorporated into the process without significantly disrupting the efficiency of the Agile process. This article briefly describes the Agile process as a primer for testers and evaluators. It will then describe the integration of systems engineering, and independent test and evaluation that is most assuredly required for development of complex hybrid tightly coupled hardware/software systems, typical of modern military and other Government agency systems.

The Agile Manifesto was written in February of 2001 by seventeen independent-minded software practitioners. The participants found consensus around four main values: 1) Individuals and interactions over processes and tools, 2) Working software over comprehensive documentation, 3) Customer collaboration over contract negotiation, and 4) Responding to change over following a plan. Agile incorporates several commonly used software delivery methods; among them are DevSecOps (DevOps with added emphasis on Security), Extreme Programming, Scrum, Feature Driven Development, and Test-Driven Development. Succinctly stated, Agile is a group of delivery methods, principles, and practices for effectively delivering software that leverages collaboration and customer feedback. Since 2001, Agile has brought structure to the process while still preserving the four values. One such methodology is the Scaled Agile Framework, or SAFe. The SAFe methodology not only provides a management and technical structure but provides a structure

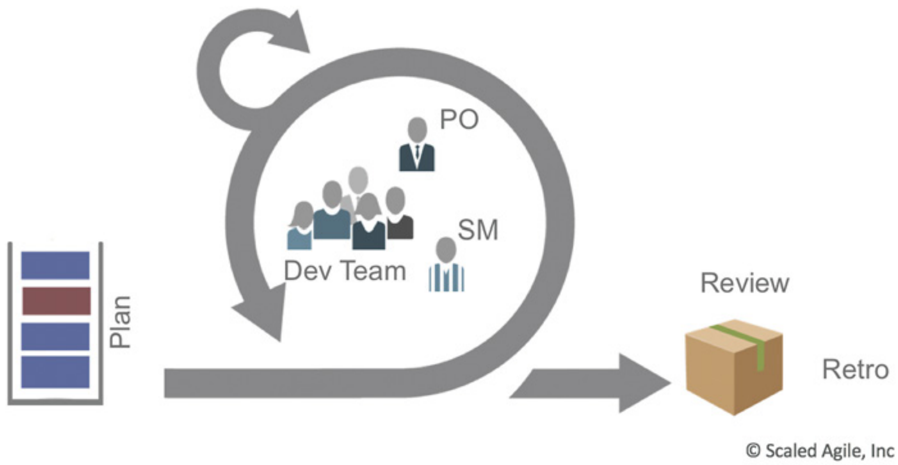

Figure 1: Agile Scrum Sprint[1]

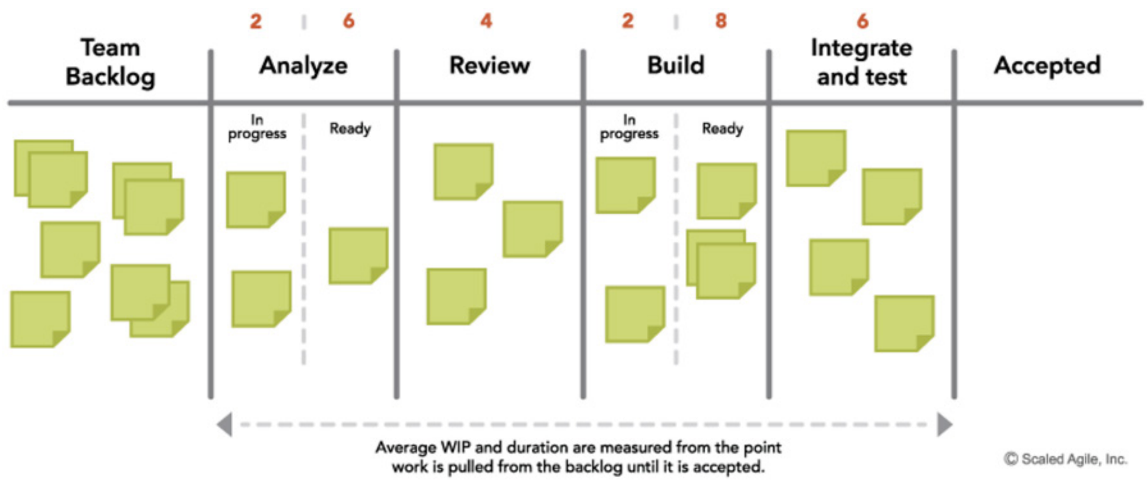

Figure 2: Kanban[1]

for scaling from a small single application development up to a large-scale portfolio development.

The basic building blocks of SAFe are the Agile Team, the Scrum, and the Sprint (Figure 1).

Agile teams are cross-functional, self-organizing entities that can define, build and test, and where applicable, deploy increments of value. A true Agile team is accountable and committed to common goals with all the roles needed to deliver value quickly, reliably, and with high quality. They typically use an Agile delivery method, such as Scrum or Kanban (Figure 2). Teams visualize and manage their flow of work in a Kanban system to optimize flow. This visualization also helps teams identify bottlenecks by defining work-in-process (WIP) limits to help teams stop working on new user stories and start finishing work. Because systems engineering was around long before Agile, it is not surprising that many elements of the systems engineering process are incorporated into the Agile development process. For instance, the Agile teams use a process very similar to systems engineering to understand the requirements as features associated with user stories, partition the work and allocate feature development to appropriate members of the team, integrate and test the features using test scripts developed from user stories, and then deliver a package that at a higher level is integrated with partitioned development products output from other teams. This is analogous to partitioning functionality to subsystems in systems engineering that are developed in parallel and then integrated into a viable capability.

Although testers are members of a closely-knit Agile development team, they work somewhat independently from the coders as they develop automated test scripts that comprehensively cover the features and user stories that the Agile team has accepted for a particular sprint. With extreme programming, software is developed using a tight mix coding and testing. Testing is complete in its coverage and builds as regression testing

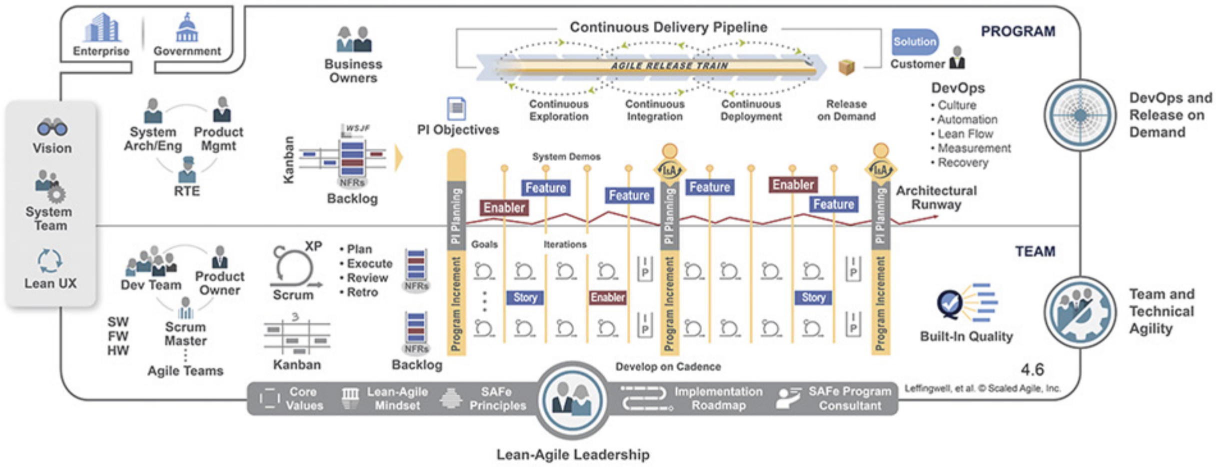

Figure 3: Essential Scaled Agile Framework[1]

throughout the program. In fact, because the testing often matures before the code to be tested, the code is simply iteratively written and tested until it passes the test. This is known as Test Driven Development.

In the Scaled Agile Framework (Figure 3), multiple Agile teams choose their features to develop during a program increment, consisting of five to six two week long sprints, starting with an integrated Program Increment Planning session, and concluding with an Innovation and Planning sprint and an Inspect and Adapt session. They work to their feature backlog that is prioritized by the Product Owner who represents the user interests and are guided and led by the Scrum Master. The work of these Agile teams is coordinated and integrated toward a solution by an Agile Release Train (ART). ARTs are teams of Agile teams that are organized to release value on demand via a continuous delivery pipeline. These ARTs generally use the DevSecOps process (Figure 4) to facilitate continuous exploration, continuous integration, and continuous deployment.

DevSecOps is a continuous process that leverages significant automation where multiple steps are conducted in parallel and incremental capability can be delivered as available. DevSecOps and Agile are often used interchangeably; however, Agile is a program/project management process, whereas DevSecOps is an engineering development process also known as a delivery method. Agile can exist without DevSecOps, but DevSecOps development integrated into an Agile program/project management framework is a great combination and now the most typical implementation.

Figure 4: DevSecOps Process

Agile Release Trains oversee and integrate multiple Agile Development Teams to provide a continuous delivery pipeline aimed at delivering value on demand. Agile Release Trains represent multiple capabilities and disciplines required to build a complete multi-feature solution, and are guided by a System Architect, a Release Train Engineer (analogous to the Team Scrum Master), and a Product Manager, who like the Team Product Owner, represents the customer/user and manages and prioritizes the Train Backlog along with the Business Owners (Figure 3).

The bottom line with Agile is to deliver incremental viable capability to the customer or user on short timelines and then rapidly respond to customer/user feedback with the next iteration. A next iteration can be as short as two to three weeks; much more responsive than the traditional Defense Acquisition System response times. This is likely why Congress, with the 2018 National Defense Authorization Act, Section 874, required the Department of Defense (DoD) to designate multiple Agile Pilot programs to determine the feasibility of integrating Agile methodologies into Defense Acquisition. There are currently sixteen Defense Agile Pilot Programs, most about halfway through their scheduled duration. While these pilot programs are showing promise for streamlining development for purely software capability, questions still remain with integrating independent T&E into Agile and what happens with tightly coupled hardware/software systems.

As described above, testing is an integral part of the

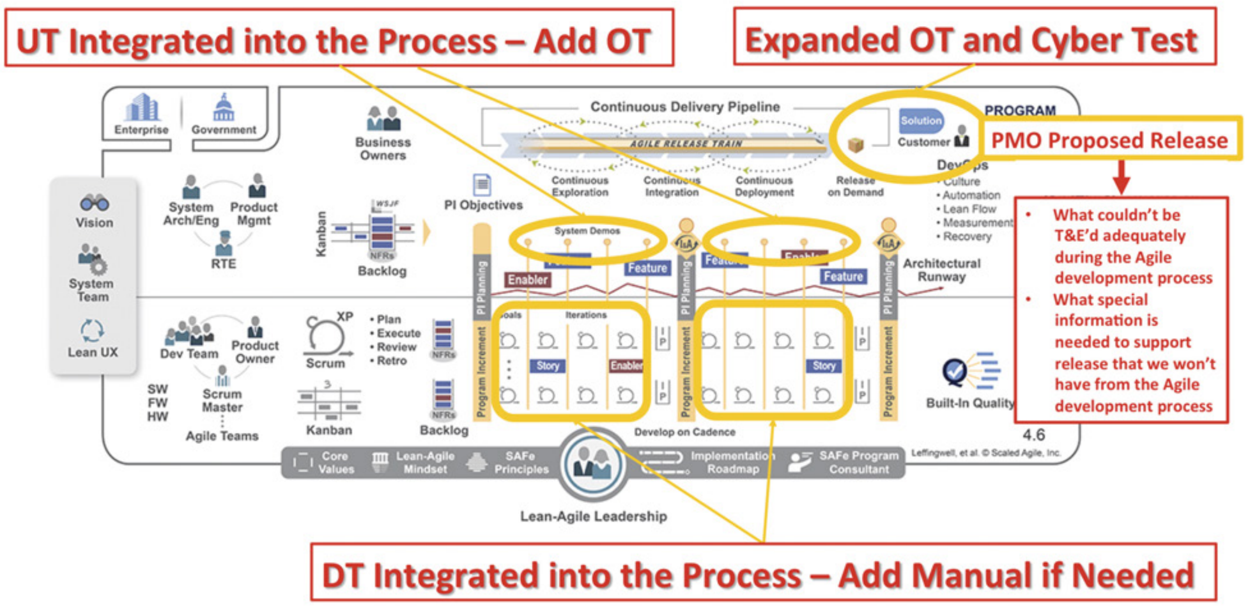

Figure 5: Integrating Independent T&E into Agile[1]

Agile development process. In fact, automated test scripts are developed along with, and sometimes in advance of, the operational code, and then the developing code is tested on a very frequent and regular basis for performance. This integrated testing covers much of developmental test needs. It also attempts to address user testing, in that the test scripts are based on user stories. However, automated tests do not have a brain, and thus are unable to think. Therefore, they simply provide a check of functionality and lack the ability to uncover usability glitches and other issues that only the human imagination in a live user environment can uncover. This is especially true when it comes to cyber security testing. Therefore, there are user demonstration opportunities built into the Agile process as indicated in Figure 5. However, most of these demonstration opportunities are not in the live/production environment, may not be with representative users or threats, and likely won't be integrated with hardware. Consequently, from an operational test and evaluation standpoint of adequately assessing solution effectiveness, suitability, and survivability/security, some operational, and even developmental testing and evaluation, will undoubtedly need to be performed just before or after release of the software. Implementation of the Agile process must allow for this, especially with development of military systems where safety and mission assurance are of vital importance to our warfighters and national security. Extensive and creative upfront planning should be able to minimize such add-on end-of-development testing.

Development of tightly coupled hardware/ software systems presents additional challenges. While hardware development may be able to adopt many of the Agile methodology tenants, it will most likely be on a much different development schedule. Figure 6 shows a scheme for integrated hardware/software development that encompasses the Agile tenant of incremental release of maturing viable capability.

During the critical beginning steps of the systems engineering process, great care must be taken during partitioning and allocation of functions. Currently with highly complex systems, much of the functionality is being allocated to software, which certainly speeds development and facilitates incremental capability delivery and evolution, especially when Agile software development is incorporated as in Figure 6. Then, the software developed using Agile methodology is integrated with the hardware, and the fully integrated system is tested before an incremental release. The magic is in minimizing long lead hardware development by minimizing functionality allocated to hardware, incorporating existing hardware, and other such strategies. A novel approach could be to develop or incorporate hardware first as the "Digital Twin" (a high-resolution, physics-based model of the hardware) that could be developed using an Agile methodology, integrated with the operational software, and demonstrated/tested as an integrated system, using the Agile concept of short iterations and incremental delivery. At some point, the hardware could be developed or incorporated and then verified and validated to the "Digital Twin".

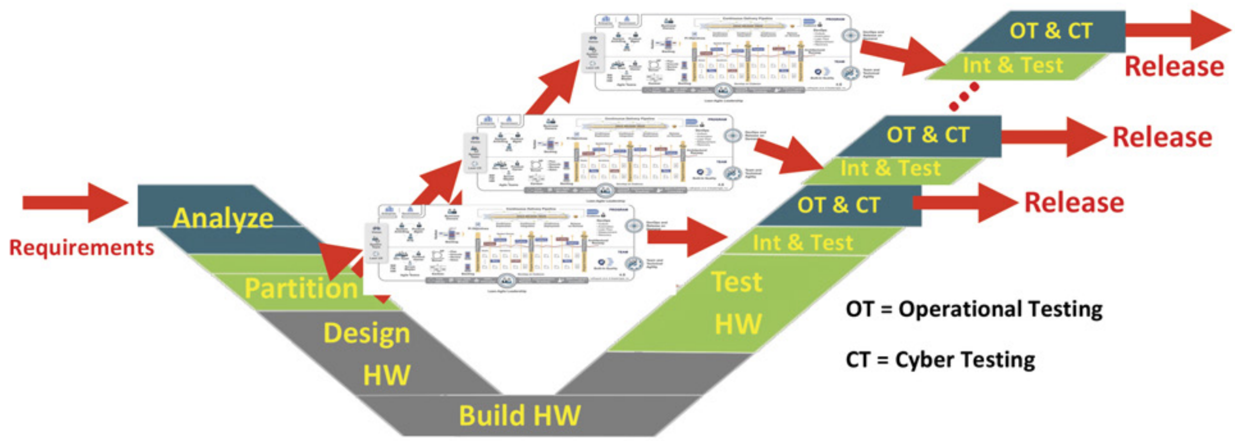

Figure 6: Integrated Agile and Systems Engineering Development[1]

Can Agile, systems engineering, and independent test and evaluation coexist and cooperate? Not only is the answer yes, but as has been discussed, Agile incorporates all essential elements of systems engineering (admittedly with a different lexicon) and includes independent developmental testing at the team level and user testing at the integration and solution level. We have also discussed that for tightly coupled hardware/software systems, Agile development functions well within a systems engineering construct. Agile, systems engineering, and independent test and evaluation thus show great potential to work together to greatly enhance the efficiency and effectiveness of the development of complex systems. ❑

WILLIAM D. (DAVE) BELL, D.E., has more than forty-nine years of professional engineering experience with extensive knowledge in the areas of basic research, systems development, systems engineering, systems integration, testing and acceptance, resource acquisition, and program administration. He retired from Federal Government service in 2005 and since 2007 has worked for The MITRE Corporation as a Principal Multidiscipline Systems Engineer. Recently he served as the Technical Director for Dr. C. David Brown who was both the DASD(DT&E) and Director TRMC. Prior to this assignment, he managed several of MITRE's Test and Evaluation (T&E) projects that support the Office of the Secretary of Defense (OSD). Since January 2004, he has taught a graduate course in Systems Integration and Test for Southern Methodist University (SMU). He has guest lectured for Johns Hopkins University (JHU) systems engineering classes multiple times and co-taught T&E for MITRE's Master's students at JHU. Dave received his B.S. in Physics from The Ohio State University, M.B.A. from National University and the Doctor of Engineering from Southern Methodist University.

C. DAVID BROWN, Ph.D., PE, CTEP, is a consulting engineer supporting DoD T&E through The MITRE Corporation and the Institute for Defense Analyses. He also teaches graduate courses in program management and systems engineering for Johns Hopkins University. He is the former Deputy Assistant Secretary of Defense for Developmental Test and Evaluation and Director of the DoD Test Resource Management Center. Throughout his 44-year career in T&E, he has held a variety of positions ranging from range instrumentation development, range test director, technology and range director, and test lead for a major Army acquisition program. Dr. Brown has a Ph.D. in electrical engineering from the University of Delaware and an M.S. in National Security Policy from the Industrial College of the Armed Forces. He is a registered Professional Engineer, was a member of the Army Acquisition Corps, and is a retired Army Reserve Colonel. He has three patents and is a Certified Test and Evaluation Professional, and a certified Scaled Agilist. He has been a member of ITEA almost since its founding and has served in numerous leadership and support positions. He was the recipient of the prestigious ITEA Matthews Award in 2016.

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Endnote

[1] Figures 1, 2, 3, and parts of 5 and 6 are © Scaled Agile Inc. Used with Permission of SAI.

Chapter News

Francis Scott Key

The Francis Scott Key Chapter hosted the 5th ITEA Cybersecurity Workshop on March 25-28, 2019 at the Water's Edge Event Center (WEEC), Belcamp, MD. Almost 200 representatives from industry, academia, and government agencies participated in the workshop, including international guests. As anticipated, participants posed interesting questions which prompted lively discussions among panelists, presenters, and audience members. FSK observed that participation is growing every year. Based on the feedback from this event, ITEA has already begun scoping topics for the next cybersecurity workshop.

On March 6, 2019, FSK welcomed Dr. Tom Donnelly, Systems Engineer in the JMP Software Division of the SAS Institute, as guest luncheon speaker at the WEEC. He provided FSK members with examples of how he has customized Design of Experiments (DOE) methods to optimize products, processes, and technologies throughout his career. Dr. Donnelly is extraordinarily qualified to discuss DOE given his background as a partner in the first DOE software company, an Army analyst, and an instructor for professional development courses.

The April luncheon at WEEC showcased our annual high school scholarship winners. This year's winners are Amy Pham, Aberdeen High School; Zachary Ewing, C. Milton Wright High School; Julianna Berte', C. Milton Wright High School; and Sage Leone,

FSK Scholarship Winners (left to right): Amy Pham, Zack Ewing, Julianne Berte', and Sage Leone

Bohemia Manor High School. FSK was honored to have Dr. Patrick J. Baker, US Army Data Analysis Center, as the Guest Speaker who encouraged the students to continue pursuing their education. Dr. Baker assisted Jim Myers, FSK VP for Education, in handing out $10,000 in scholarships. This luncheon is FSK's capstone event given our mission is to promote education in Science, Technology, Engineering, and Mathematics. Congratulations to these deserving winners.

COL John Hall, Commander of the US Army Aberdeen Test Center, spoke to FSK members on "The Future of Testing" during our annual Professional Awards luncheon. He described how the Test Center is adjusting to accommodate the fast pace required by the Army Futures Command. It was fitting to have the Commander of ATC speak at this year's ceremony as all three award winners were from ATC. Brian Reed was awarded the Young T&E Professional Award, Don Hirt was presented with the T&E Professional Award, and Charles Valz won the General Powers Award for a lifetime achievement in the field of T&E. COL Hall assisted Fred Merchant, FSK VP for Programs, in handing out the Awards. Congratulations to all our winners and special

FSK Professional Awards Winners, (left to right): Guest Speaker, COL John Hall, ATC Commander; Charles Valz; ATC, Genera Powers Award; Don Hirt, ATC, T&E Professional Award; Brian Reed, ATC, Young T&E Professional Award; and John Wallace, ATC Technical Director.

congratulations to Mr. Valz who retired from ATC in May.

FSK is pleased to host Robert Miele, Technical Director of the Army Test and Evaluation Command, as the guest speaker at the final WEEC luncheon before the summer hiatus. For more information on FSK, please visit our website at https://fskitea.org/.

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Emerald Coast Chapter

The ITEA ECC held a social in conjunction with Test Resource Management Center Combined Midyear Review being held at the Doolittle Institute in Niceville, FL near Eglin AFB. This was a great opportunity for local ITEA members to meet Test and Evaluation (T&E) professionals from almost every T&E range in the MRTFB. Among those pictured are National Board Member, Pete Crump; Chapter President, Gene Hudgins; and local board members Chris Brunson, Min Kim, Bob Baggerman, John Rafferty, and Scott Thompson.

Emerald Coast Chapter social hour at Props Ale House. Among those pictured are National Board Member Pete Crump, Chapter President Gene Hudgins, local board members Chris Brunson, Min Kim, Bob Baggerman, John Rafferty, and Scott Thompson.

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Association News

Nominations Sought for the 2020 ITEA Board of Directors

ITEA Board of Directors Nomination Form

This notice is to announce the 2019 election process for the 2020 ITEA Board of Directors and to advise the ITEA membership of the nominating process.

The purpose of the Board of Directors is to undertake management of the business and affairs of the Association. The goal of the election process is to ensure the Board represents a broad spectrum of the T&E community; a mirror of the functional diversity of the community to include members of the technical, management, policy, and analysis sectors.

There are two categories comprising the Board of Directors, **Elected** members and **Appointed** members.

- **Elected Directors:** The number of elected Directors of the Association is currently eleven. An elected Director will serve for a period of three years. An elected Director may not serve for more than two consecutive terms.

- **Appointed Directors:** For the purpose of diversification, the Board of Directors may appoint up to four additional Directors for terms of one year; renewable no more than two times.

For the 2019 elections, the committee will seek candidates to fill the following vacancies:

- **Elected Directors: Four Positions**

- **Appointed Directors: Not to exceed four Positions**

Elected Directors will each serve 3-year terms from January 2020 through December 2022 and will be presented to the membership during the 2019 Annual Symposium, which will be held at the **Kaua'i Resort** in Lihue, HI, November 12-15, 2019. Any Director **appointed** by the Board will serve for one year (2020).

The Elections Committee, a standing committee of the Board chaired by Matt Reynolds, oversees the nomination and election of Directors. Nominations are openly solicited from ITEA Chapters, the Board of Directors, the Senior Advisory Board, Corporate members and Individual ITEA members. The Elections Committee will follow the ITEA Bylaws and established policies of the Association in evaluating nominations for the Board of Directors and developing the slate for balloting.

Nominations for elected or appointed positions are to be submitted via the attached nomination forms. Nomination forms are also available on the ITEA web site at: www.itea.org.

Nominations must be submitted no later than June 30, 2019, in order to be considered. Please send completed nomination forms to James Gaidry, ITEA Executive Director, at jgaidry@itea.org, or via fax at 703-631-6221.

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Call For Nominations – Test & Evaluation Professional Awards

The period of performance for the 2019 T&E Professional Awards is from July 1, 2018 to June 30, 2019. Nominations are due by July 27, 2019.

ITEA is proud to honor those that advance the T&E community through their contributions to both the T&E Profession, as well as to the Association. ITEA presents six ITEA T&E Professional Awards which recognize contributions to the T&E Profession, and four ITEA Awards which recognize contributions to the Association. These awards are presented at the ITEA Annual International T&E Symposium.

Please visit http://www.itea.org/awards for nomination forms and more information. All nominations should be sent to awards@itea.org.

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ITEA WANTS YOU!

Call for Volunteers

Volunteers are at the heart of our Association, and our strength is a result of the time and effort provided by those who volunteer to serve. ITEA offers many opportunities at the local, regional, and international levels for its member to contribute their time, talents, and energy by giving back to the test and evaluation industry, helping us advance the profession and supporting the Association. If you want to become part of the ITEA volunteer team, now is the time to let us know.

The following volunteers have graciously offered their time, talents, and energy to serve as Committee Chairs for the Association. But, they cannot do it alone. They need YOU!

Awards Committee - Conducts an annual awards program with an awards presentation ceremony at the annual international symposium. Stephanie "Steph" H. Clewer, Chair.

Events Committee - Plans, schedules, and supports a multi-year calendar of ITEA-sponsored and co-sponsored symposia, workshops, and conferences. Doug Messer, Chair.

Professional Development Committee - Plans and develops professional development programs and education curriculums in T&E that increase the knowledge, skills and abilities of ITEA members, advance the field of T&E, and elevate the status of the T&E professional. Oversees ITEA's scholarship program. Peter Christensen, Chair.

Publications Committee - Develops and maintains a formal publications program including publishing quarterly *The ITEA Journal* and sponsors publications concerning test and evaluation. Steven "Flash" Gordon, Ph.D., Chair.

If you have experience, passion, and a willingness to share, please consider participating as a volunteer on one of these committees. One of our goals is to have volunteer groups that represent the diversity of backgrounds, experience, and demographics of the test and evaluation community. Please contact James Gaidry, CAE, ITEA Executive Director, by e-mail at jgaidry@itea.org, or at 703-631-6220, for more information.

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GET CERTIFIED!

Elevating the Test and Evaluation Profession with a Globally Recognized Credential

ITEA administers, manages, and awards the Certified Test and Evaluation Professional (CTEP) credentials that provides significant benefits to T&E professionals, organizations, and their customers. The CTEP designation recognizes those individuals who demonstrate the following: They meet the minimum level of competency in the requisite Knowledge, Skills, and Abilities (KSAs) that have been identified by T&E subject-matter experts (SMEs); their commitment to maintain currency in the field; and, their dedication to advancing the profession.

The CTEP requires a candidate to have the following:

- A baccalaureate degree from an accredited college or university, preferably with a major in engineering or a related technical field, AND a minimum of three years of relevant work experience, OR,

- An associate degree from an accredited college or university, preferably in a technical field, AND a minimum of five years of relevant work experience, OR,

- A minimum of ten years of relevant work experience.

Please visit www.itea.org/certification to apply and to obtain more information, or contact James Gaidry, CAE, ITEA Executive Director, by e-mail at jgaidry@itea.org, or at 703-631-6220, x204.

Certified Test and Evaluation Professionals

The following individuals have been awarded the Certified Test and Evaluation Professionals (CTEP) designation, which recognizes those individuals who demonstrate the following: They meet the minimum level of competency in the requisite Knowledge, Skills, and Abilities (KSA) that have been identified by T&E subject-matter experts (SMEs); their commitment to maintain currency in the field; and their dedication to advancing the profession.

Please join us in congratulating these T&E professionals on their achievement!

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Journal Specifications

Trim Size: 8 1/2 x 11 inches. Journal trims 1/8 inch off top, bottom and outside edge. Live matter should be a minimum of 1/2 inch inside the trimmed edges, and a minimum of 1/2 inch should be allowed for the bind.

Ad Sizes (width x height):
Full Page - 7 1/2″ x 10″
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Add 1/4 inch for bleeds.
1/2 page = 6 1/2″ x 4 1/8″
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Graphics: Should be a minimum of 300 dots per inch.

Formats: We accept PDF, TIFF, JPEG or EPS formats for both Mac and PC platforms. All fonts must be embedded.

Disclaimer: All claims for errors in advertisements must be made in writing and received within ten days of publication and will be considered only for the first insertion of the advertisement.

2019 Production Schedule

Issue	Space Reservation Due	Ad Material Due
March	12/28	1/4
June	3/22	4/5
Sept.	6/21	7/5
Dec.	9/20	10/4

Ad Type	ITEA Partner Rates (ITEA Corporate Members, Sponsors, and Exhibitors)			Standard Rates		
	1x	2x	4x	1x	2x	4x
Cover 2	$2500	$2200	$2000	$3000	$2700	$2500
Cover 3	$2420	$2120	$1920	$2900	$2600	$2400
Cover 4	$2740	$2440	$2240	$3300	$3000	$2800
	4-Color					
Full page	$2100	$1800	$1600	$2500	$2200	$2000
1/2 page	$1700	$1400	$1200	$2000	$1700	$1500
1/4 page	$1300	$1000	$800	$1500	$1200	$1000
1/8 page	$500	$400	$300	$800	$650	$500
2-pg spread	$3300	$3000	$2800	$4000	$3700	$3500
	Black/White					
Full page	$1620	$1320	$1120	$1900	$1600	$1400
1/2 page	$1300	$1000	$800	$1500	$1200	$1000
1/4 page	$900	$600	$400	$1000	$700	$500
1/8 page	$300	$250	$200	$450	$350	$275
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