Talking Back—Weapons, Warfare, and Feedback

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Introduction

A man who wants to make a good instrument must first have a precise understanding of what the instrument is to be used for; and he who intends to build a good instrument of war must first ask himself what the next war will be like.

–General Giulio Douhet

The Department of Defense (DoD) has no shortage of weapons programs that are over cost, behind schedule, and defunct of performance. The Government Accountability Office (GAO) has released multiple reports stating that the DoD's management of major weapons systems is high-risk and in need of reform.[1] For example, the Joint Strike Fighter (JSF) program is expected to be over cost and behind schedule "primarily because of contract cost overruns and extended time needed to complete flight testing."[2] The JSF program, DoD's most expensive acquisition, is experiencing trouble manufacturing and developing test aircraft even though DoD continues to heavily invest in it. Without test data to support performance specifications, DoD is expected to "procure 273 aircraft, costing an estimated $42B before completing flight testing."[3] Congress recently passed weapon systems acquisition reform in an attempt to reign in problems with major weapons programs by increasing oversight and communications. While GAO identified numerous areas where improvements are necessary, this article will focus on technologies to support the timely development and improvement of DoD weapons systems.

When operational users have a problem with a weapons system, they seek assistance from the acquisition workforce to address and correct problems. Operational employment data is requested in order to begin replicating the conditions of the issue. This data is usually gathered from pilot reports, with the help of recorded cockpit or weapons system audio and video, when available. This data is usually incomplete as government and contractor testers and developers generally conduct analysis and evaluation with instrumented test weapons modified to capture and telemeter high-fidelity data.

Currently DoD engages in integrated test and evaluation (IT&E) in order to improve risk mitigation by introducing operational test and evaluation (OT&E) earlier in a program's life cycle. Operational test is conducted by operational users in actual or operationally representative environments and scenarios in order to evaluate suitability and effectiveness, often developing or refining tactics, techniques, and procedures. However, "[d]evelopmental test and evaluation (DT&E) is an engineering tool used to reduce risk throughout the defense acquisition cycle."[4] DT&E efforts are often specifications compliance assessments during the development of a system, with decreasing influence as a system nears operational capability. The current testing paradigm, while intending to integrate these two efforts, is in reality coordinated DT&E and OT&E with little overlap, vice true integration. This distinction

Article Acronyms

AIM – Air Intercept Missile
ALIS – Autonomic Logistics Information System
AMRAAM – Advanced Medium Range Air-to-Air Missile
CEO – Chief Executive Officer
DoD – Department of Defense
DT&E – Developmental Test and Evaluation
ENIAC – Electronic Numerical Integrator and Computer
GAO – Government Accountability Office
GPS – Global Positioning System
ID3 – Integrated Design, Development, and Deployment
I-DAP – In-flight Data Acquisition Pod
iNET – Integrated Network-Enhanced Telemetry
IT&E – Integrated Test and Evaluation
JDAM – Joint Direct Attack Missile
JSF – Joint Strike Fighter
JSOW-C-1 – Joint Standoff Weapon
NATO – North Atlantic Treaty Organization
NEW – Network-enabled Weapons
OT&E – Operational Test and Evaluation
PHM – Prognostics and Health Management
PIN POINT – Precision Instrumented Networked Propelled Ordnance-Interchangeable
US – United States

is important to understand in light of current development programs. Referring back to the JSF program, the DoD agreeing to buy articles without an assessment of performance, has accepted "undue concurrency of development, test, and production activities and the heightened risks it poses to achieving good cost, schedule, and performance outcomes."[5] The current weapons systems acquisition context is one of budget and schedule overruns and performance deficits. While this is a reflection of larger policy issues, there are areas where technology can assist in cost, schedule, and performance goals.

DoD is under pressure to reduce time in the weapons acquisition process. "At the program level, the key cause of poor outcomes is the approval of programs with business cases that contain inadequate knowledge about requirements and the resources—funding, time, technologies, and people—needed to execute them."[6] This article is focused on technology to reduce the time between conceptualization and fielding of weapons while increasing the technology knowledge base for a particular system. During the development of weapons systems, DoD engages in testing efforts to gather weapons specifications, performance, reliability, suitability, and effectiveness data. Much of this testing is done with instrumented weapons, on test ranges, in simulated environments, and against simulated threats. Developmental and operational flight testing attempt to conduct tests in operationally representative environments and actual operational environments when possible. However, actual operational usage of weapons systems provides a host of data in actual operational environments that goes untapped.

Technology Trend Impact Analysis

The way we make war reflects the way we make wealth.

–Alvin and Heidi Toffler

Throughout American history our technology has directly impacted how we make war. The evolution of the United States has included agrarian, industrial, and information revolutions. Our warfare capabilities have incorporated aspects of each of these revolutions in attempts to improve effectiveness and efficiency. The nature of war has thus evolved to encompass isolated face-to-face combat, mass destruction, and the information warfare paradigm of today.[7] The information warfare paradigm spans the range of military operations from command and control to psychological operations, from direct attack to cyber attack. The Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms,* defines information superiority as "the operational advantage derived from the ability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."[8] A key enabler of the information warfare paradigm is the network and increased connectivity. The following is an excerpt from the Chairman of the Joint Chiefs of Staff Joint Capability Areas framework.

> Network Centric: The ability to provide a framework for full human and technical connectivity and interoperability that allows all DoD users and mission partners to share the information they need, when they need it, in a form they can understand and act on with confidence, and protects information from those who should not have it.[9]

Current information communications technologies directly impact our warfighting capabilities by enabling us to bring weapons effects on a target faster, over greater distance, and more precisely. However, when it comes to weapons development and improvement, a key link between the warfighter and the weapons developer has remained in the industrial age. This link between the warfighter and the weapons developer needs to be supported by the same information communication technologies that are enabling the evolution in tactical operations. This link will be via a user centered, networked, data gathering weapon.

Information communications technology can improve the link between the fleet user and the future requirements and development or improvement processes by capturing the data and information available in real-world training and tactical missions. This data can be fed directly into real-time decision cycles to change some aspect of current tactics or used to develop updates to the current systems or follow-on weapons. The type, frequency, and fidelity of data can be user selected via mission planning systems to provide a particular data set based on user requirements. In training, the user may want to see various types of information that will support building habit patterns, reviewing procedures, and enhancing learning processes, while experienced fleet users may want data that provides information on tactical advantages, employment recommendations, or real-time systems health. Examples of this type of data are the same types of data that operators use in training today, to include: ranges, angles, and closure rates. Embedding the acquisition of this data into the weapons systems, which the operator can use later to reconstruct employment timelines or review procedures, enables enhanced training and debrief capability as well as data to support suspected hardware or software malfunctions and potential causes. This combination of technologies and processes, used mainly in DT&E and some OT&E, should be expanded to operational use.

The technologies required to gather and transmit user specified information are currently available in disparate systems and need to be synthesized into future weapons concepts. Examples of these types of weapons are the instrumented test assets that are used by DT&E personnel. While the fidelity of information required for test and evaluation may not be required by fleet users, some level of data acquisition will enable this improved linkage between users and designers. Information communication, storage, and computing technologies are currently revolutionizing system development, operations, maintenance, and logistic processes.

Computing and Communication Technology Trends

From the dawn of automated computer hardware with the invention of the Atanasoff-Berry Computer in 1937,[10] to the current computer software and network-driven information age characterized by social networking and network centric warfare, the military has maintained a close relationship with the development of computing and networking theory, hardware, and software. Soon after the invention of the first computer, the military, spurred by the outbreak of World War II, partnered with the University of Pennsylvania to develop the electronic numerical integrator and computer (ENIAC) to compute ballistic firing tables.[11] From the Internet to the Radar processor, from the computer programming language compiler to the data-link, the military has influenced and benefitted from computing and

communications innovation. These trends are still shaping society and therefore military weaponry.

Based on the so-called laws (actually heuristic planning goals, predictions, or observations) of Gilder, Metcalfe, and Moore, the future of computing and communications technologies will provide opportunities to transform the paradigm for weapon system development and improvement. The three laws were chosen as they represent widely accepted guides for the information and communications technology industries.

Gilder's law states that "bandwidth increases threefold each year."[12] Futurist George Gilder's law comes from a concept known as Winners' Waste, which means that business models will exploit less expensive resources and conserve expensive resources. Computer processing power and bandwidth are currently the less expensive resources compared to personnel, and so the trends follow that socioeconomics will rely more on networks and computers.

Metcalfe's law states that "…the value of the network increases in direct squared proportion to the number of persons or things connected to the network."[13] This law is named after Robert Metcalfe, inventor of the Ethernet and cofounder of the 3Com Corporation. While defining *value* may be difficult, the benefit of this heuristic is in the importance it bestows on networking. Over the last 20 or more years the trend toward networking has created new ways to engage in many daily tasks, from phone calls and messaging, to research and publishing. Networking is also prevalent in warfare (will be discussed later). The amount of value espoused in the law is less important than the presence and relationship of value. The more connections, the more valuable a network is.

Finally, one of the more common computing trends, described by Moore's Law, states that "the number of transistors on a chip doubles every 18 months."[14] Gordon Moore, cofounder of the Intel Corporation, stated in 1965 that "complexity for minimum component costs has increased at a rate of roughly a factor of two per year."[15] Over the next 10 years he would refine that to a 2-year period.[16] Computer processing speeds have managed to double in capacity between one and two years since then. This performance prediction refers to the state-of-the-art technology, but for those left in the wake of the leading edge there are still implications from Moore's law. This trend also means that for a baseline of performance the cost will be reduced by about one-third every year or about one-half every 18 months. As costs have come down over time, the ability to field smart and network-enabled weapons has come to fruition.

In comparison, Moore's law is outpaced by Gilder's law and thus Metcalfe's as well. In Gilder's terms the cheaper resource of bandwidth is utilized to connect systems. The rate of advance of bandwidth is almost twice as much as processing power (doubling every 8 months compared to 12 months for Moore's law). Therefore, according to Gilder, the resource to exploit at this time is bandwidth. As we utilize bandwidth, we will realize an increased value in our networked systems, according to Metcalfe. Again it is important to realize that these laws are not laws of physics. They do not allow for performance or effectiveness comparisons, as they do not have a common frame of measurement. Their real use is in big picture trends, and the overall trend is one of self-perpetuating growth. In reference to future weapons, the next step is to develop optimizing capabilities into the weapons themselves that enhance connectivity and bandwidth. Operational weapons feedback capitalizes on this increased processing power, connectivity, and bandwidth by enhancing weapons with an optimizing capability that is customizable to testers, trainers, or tacticians.

In the computer world there is an anonymous and humorous saying that "what Andy giveth, Bill taketh away." The saying is referring to Andy Grove, then chief executive officer (CEO) of Intel, a computer chip manufacturer and Bill Gates, the CEO of Microsoft, a software manufacturer. In other words, as computer hardware gets faster, computer software will be developed to capitalize on the improved capability. While it seems intuitive that as the technology gets better the applications of the technology get better, what may not be so intuitive is that this capability excess creates a self-sustaining vortex. There is always something big and new on the horizon. In the last 20 years graphical user interfaces, Web-browsing, massive search engines, and hand-held computing have become accessible to millions. Corporate America is exploiting these trends and adapting business and workforce models to match. DoD must do the same. However, in approaching this new paradigm it is important to keep another computing industry law in mind, Amara's Law, which states that "[w]e tend to overestimate change in the short run, and underestimate it in the long run."[17] There are no magic bullets, even if they are networked and instrumented.

Weapons Technology Trends

Network and Data-Link Capability. Network-centric warfare synthesizes the capabilities of ground power, sea power, air power, electronic warfare, intelligence, surveillance, reconnaissance, command, and control into a revolutionary capability that transforms the speed and efficiency with which wars are fought. According to the *Joint Vision 2020* and *Joint Capability Areas,* DoD and Service leaders have supported the trend toward network-centric warfare and the development of hardware and software architectures to support it. According to the pioneers of network-centric warfare theory, Arthur K. Cebrowski and John J. Garstka, network-centric warfare enables a shift from an entrenched to a dynamic warfare style characterized by speed and self-synchronization.[18]

Network enabled weapons (NEW) represent the current trend in precision strike weaponry. Traditional weapons systems generally rely on a single source to provide aim point, update, or guidance information to engage targets. The trend in strike weapons engagement has evolved from unguided bombs to guided variants, while generally relying on a single source of information and one-way communications. Guided weapons include the infrared or heat-seeking Air Intercept Missile (AIM)-9X Sidewinder; active Radar-guided AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM); Global Positioning System (GPS) aided Joint Direct Attack Munitions (JDAM); laser-guided weapons such as the Paveway bomb series and Laser Maverick air-to-ground missile; single-source data-link weapons such as Walleye and the Standoff Land Attack Missile-Extended Range (SLAM-ER); and the first network-enabled weapon, the Joint Standoff Weapon, JSOW-C-1.

Technology trends have allowed for affordable, small form factor, open architecture radios to be integrated into current weapons. While the current data-link architecture for NEWs is Link-16, the analysis in this article applies to future weapons in general. Link-16 is a North Atlantic Treaty Organization (NATO)

standardized data exchange format. Military Standard 6016, *DoD Interface Standards, TADIL J Message Standard*, defines the Link-16 message format. Link-16 enables sea, air, and land forces to exchange situational awareness, targeting, and employment data in near real time. Link-16 supports the exchange of position and status, text, imagery, and up to two channels of digital voice (2.4 or 16 kilobits per second [kbps]).[19] "The hardware component of Link-16 is the Joint Tactical Information Distribution System (JTIDS) or, its successor, the Multifunctional Information Distribution System (MIDS). These high capacity, ultra high frequency (UHF), line-of-sight (LOS), frequency-hopping data communications terminals provide secure, jam-resistant voice and digital data exchange."[20] The network is critical to the future of warfare.

Data Acquisition and Management

DoD is engaged in an effort to overhaul the telemetry capability of national test and evaluation complex. The integrated Network-Enhanced Telemetry (iNET) program's "goal is to find a feasible upgrade for the basic architecture of the test and evaluation ranges' telemetry systems"[21] One aspect of iNET being currently developed is the Telemetry Network System (TmNS) which "will provide its installations' computer networks with a wideband wireless capability that covers hundreds of square miles. As a result, flight test centers will be able to dynamically adjust the spectrum required for test vehicles." Along with wireless network hardware to upgrade currently aging telemetry systems, iNET will also enable a more efficient use of the frequency spectrum so that bandwidth is not wasted, and it is available when needed.[22] One of the added benefits of the new technologies will be the capability for "program managers and aircraft manufacturer personnel to monitor tests from off site."[23] Data acquisition technologies are not only apparent in the test and evaluation community, but they are also gaining momentum in the operational community.

The JSF is a watershed weapon, marking today with the network and data enhanced weapons of tomorrow. Take for example the JSF Prognostics and Health Management (PHM) System and the Autonomic Logistics Information System (ALIS) which stand to revolutionize aircraft operations and logistics support via automated and networked information communications technologies. At a conference for life-cycle management Captain Simon Henley (United Kingdom Royal Navy), Andrew Hess, and Leo Fila presented a paper on the JSF PHM and ALIS systems. The following is an excerpt from their presentation.

> The JSF program is supported by the automation of the logistics environment such that little human intervention is needed to engage the logistics cycle. Actions that will be automated within the JSF supportability concept include maintenance scheduling, flight scheduling, ordering spare parts, and the like. The cornerstone of autonomic logistics (AutoLog) is an advanced diagnostic and Prognostics and Health Management (PHM) system. The PHM provides the data, information, and knowledge for initiating the AutoLog chain of events. PHM is the ability of the aircraft to do fault detection (FD), fault isolation (FI), and accommodation real-time on board the aircraft. The PHM architecture will directly interface with [ALIS], which is the information system that will enable the autonomic logistics functions. The [ALIS] could automatically forward to the original equipment manufacturer (OEM) data on problems that arise within the fleet, thus alerting them to a developing situation sooner and enabling them to provide faster, cheaper fixes to these problems.[24]

Data is the lifeblood of the PHM and ALIS systems. The network (wired and wireless) is the vascular system. The nervous system is the web of sensors dispersed in key locations in the aircraft and work spaces. Humans are the muscular system that gets it all going in the right direction. Together these systems bring new life and capability to the operations and support systems. Operational weapons feedback is a concept that aims to do the same for weapon systems development and improvement by harnessing, processing, and sharing data.

In translating test, training, or tactical information into useful knowledge that will aide in the development or improvement of weapons systems, the networking of weapon systems with customizable data acquisition and analysis capabilities will move weapons (and thereby the product life-cycle process) further up the hierarchy of knowledge. Connected weapons supported by data acquisition templates or algorithms that are based on the user's specific needs will provide not only data, but information and at times knowledge. As systems thinking pioneer Dr Russell Ackoff defines it, the "application of data and information [which] answers 'how' questions."[25] Questions such as, How can the warfighter use what they have more effectively? And how can the warfighter adapt what, they the warfighter, have to get the new capability he or she wants?

The Apple iPhone and Microsoft Windows are examples of products that are continuously being improved by networked systems and automation. The products, processes, technology, and business models support the workforce at each of these companies, enabling innovative and market competitive products. Widespread and connected usage actually enhances the development and update processes by enabling Apple and Microsoft to collect information about system performance, deficiencies, user preferences, and more. The testing and development efforts of Microsoft are enhanced by automated feedback from users. The downloadable applications and customizable interfaces allow users to optimize the iPhone to his or her personal or professional liking. If we want to reduce the time required to field effective weapons systems in DoD, then we must adapt our weapon systems to do the same. The synthesis of future communications, computing, and networking technologies provides an enabling vision for the future.

Future Concept of Operations

Too often we forget that genius, too, depends upon the data within its reach, that even Archimedes could not have devised Edison's inventions.

–Ernest Dimnet

Future Concept of Operations Vignette

The year is 2030 and international tensions over energy resources threaten to escalate into hot war. The United States Armed Forces have increased their operational tempo, conducting more exercises with the dual purpose of calming tensions via presence and also preparing for operations in a multi-theater conflict. US land forces are spread thin around the globe, US maritime forces are forward deployed on long rotations to ease the interdeployment readiness cycle, and US Air Forces are

conducting around-the-clock expeditionary flight operations.

The US Air Forces are a mix of fourth and fifth generation manned fighters and unmanned strike, intelligence, surveillance, reconnaissance, and communications platforms. The weapons suite has evolved to include a highly precise, low yield variety of weapons that are designed to surgically remove key enemy personnel or infrastructure nodes. Directed energy and nonlethal weapons have also reached full operational capabilities. One particular weapon development that has reached initial operational capability and has been recently deployed is the Precision Instrumented Networked Propelled Ordnance-Interchangeable (PIN POINT). The PIN POINT program began as a cooperative development between government, industry, and research labs via a shared knowledge base of past weapon system data. The design objective was to create the true jack-of-all-trades air warfare weapon. PIN POINT is a modular weapon making it easy to update and integrate. The warhead is reconfigurable (thermobaric high explosive, electromagnetic pulse, tungsten fragment, and propulsion augmented) to enhance the effectiveness of the small weapon. The sensor and guidance section is also interchangeable (millimeter wave, infrared/laser, electro-optical, acoustic, and Radar homing). The weapon is the size of a small legacy air-to-air missile, supporting internal and external carriage on all existing manned strike aircraft as well as all full size unmanned aerial vehicles.

The weapons are network enabled via the encrypted Link-X data-link network. PIN POINT is also able to capture data onboard and telemeter that data back to host platforms via data link. The data sampling rate is adjustable depending on the level of data needed, from single samples per second to the low thousands per second. The sampling rate can also be automated via selection in preflight mission planning. The data transmission rate is adjustable and controlled by automated processes dependent on phase of employment and type of data to be transmitted.

Fleet use has continued to optimize the weapon's autopilot algorithm, sensor gains, and warhead effectiveness models via direct feedback from developmental testing, operational testing, and operational usage. Recently, information on Eastern Europe and Northern Arabian Gulf climate effects on seeker and propulsion modules was collected from PIN POINT weapons being used by forward deployed Air Force and Navy squadrons. This information was fed back into the AWIX System (Automated Weapons Information Exchange), the secure weapons data repository and analysis system for DoD. The updated information was integrated into the contractor software models and used to develop the latest autopilot and employment profile which will be included in the weapon's next software update. Software updates are done by physical connections like most legacy systems as well as by secure data link. Generally the land-based Air Force squadrons use physical connections because of the increased reliability, while sea-based squadrons use the wireless capability to upload software because of space constraints on aircraft carriers.

The first operational use of PIN POINT was during a Joint exercise in Alaska known as Northern Edge. The target was located and tracked via an airborne early warning aircraft, and the track file information was passed to a manned fighter via Link-X data-link. The manned fighter assigned weapons priority to the track file, which was designated as hostile. The fighter was directed to engage the hostile (a low-cost drone aircraft). The manned fighter then assigned targeting to an unmanned air combat vehicle, which was carrying the PIN POINT weapon. The unmanned air combat vehicle intercepted and engaged the drone from its left side. The drone was crossing from right to left in front of the unmanned fighter as it approached the launch point. The weapon sent a cue to the operator of the unmanned system to turn slightly to the left prior to firing the weapon. The operator complied and the weapon was fired once the shooter was in the launch acceptability region. The weapon closed on the drone and just prior to impact the data acquisition rate was increased to the maximum sample rate and the telemetry stream increased to maximum bandwidth to relay real time target maneuver updates to the Link-X track file and video of the weapons sensor image until impact. The drone's preplanned evasive maneuver was no match for the PIN POINT's maneuverability. Splash one! The first operational PIN POINT employment was a massive success for the PIN POINT team as well as the Joint find, fix, target, track, engage, and assessment kill chain.

Post flight the data was downloaded from the aircraft data transfer unit in the unmanned air combat vehicle as well as a data stream from the manned fighter who assigned the targeting. The airborne early warning platform also had target state information that was transmitted via Link-X back to the network operations center at Elmendorf Air Force Base since the aircraft would remain airborne to support an upcoming exercise. The on-site analysts and off-site contractors viewed the event and associated data stream in real time. The program manager drafted a quick-look report which read, "Congrats Team PIN POINT, the first operational PIN POINT shot matched the modeling and simulation data. This event was a success for the integrated product team, the program office, and most of all–the WARFIGHTER!" The analyst and engineers; however, were already hard at work reading through the system flags and cues (weapon generated indicators of potential issues or suggestions for improvement) and looking for ways to improve pilot or operator cueing, flight profiles, and data automation algorithms.

How Do We Get There From Here

Currently most weapons have no requirements for data acquisition. Weapon requirements are focused on weapons employment, logistics, and support. Excluding DT&E efforts, weapons data is currently limited to visual and auditory cues. Examples of potential data feedback for a few select weapons are (to include but not limited to) as follows.

- Aim-9X Sidewinder: seeker acquisition and track range, seeker video, presence of countermeasures.
- AIM-120 AMRAAM: onboard Radar active, onboard Radar acquisition, presence of countermeasures.
- Paveway Series Laser Guided Bombs (LGB): seeker acquisition, seeker track, seeker track lost, impact velocity, impact angle.
- Joint Direct Attack Munitions (JDAM): align quality, satellite vehicles tracked, signal jamming, impact velocity, impact angle.
- Joint Standoff Weapons (JSOW): align quality, satellite vehicles tracked, signal jamming, impact velocity, impact angle, seeker video.

Once appropriate data requirements have been identified and codified, the data has to be acquired and transmitted. Current aircraft hardware and software support data transmission to and from weapons while connected to the aircraft (as is required for GPS-aided weapons such as JDAM and JSOW). This utility needs to be expanded to all weapons and dedicated hard drive space apportioned for storage and retrieval of weapons information, audio, and video. For example, the AIM-9X uses a system called the In-flight Data Acquisition Pod (I-DAP) during DT&E flights to capture data from the missile. The I-DAP has an internal high-capacity flash memory drive. "The I-DAP also monitors and records the Mil-Std-1553, *Aircraft Internal Time Division Command/Response Multiplex Data Bus,* traffic to the missile. Analog real-time video of the missile seeker is provided out to the launcher pylon connector. A ground station (personal computer with large capacity disk drives) is used to download the data from I-DAP, after the aircraft returns to the base." For operational weapons the data storage hardware should reside in the aircraft due to the possibility of employing the weapon, while captive training rounds could contain on-board storage.

Collected weapons data also needs to be transmitted when weapons are in flight. The current capabilities for data transmission are tactical and Radar data-links. Based on the previously analyzed trends Link-16 (and any future follow-on system) will be the focus. Link-16 is the most common tactical data-link in DoD aircraft. The data rates and security of tactical networks need to be improved. The bandwidth needs to be able to support high resolution imagery and video. For comparison, DT&E "flight test instrumentation systems collect more than 200 megabits of data per second, [and] data transmission rates remain at 5 megabits per second."[26] While the test and evaluation enterprise is aiming to improve this data acquisition and transmission capability, this is a good place to start for operational weapons. These data rates currently support high fidelity data acquisition and transmission to include voice, imagery, and video.

Integrated Design, Development, and Deployment (ID^3)

Operational weapons feedback capability will enable continuous product improvement of fielded weapons by integrating phases of the product life cycle. By connecting the weapons and user processes via automated data processing, systems will be continually monitored or assessed for product and process improvement. Data on usage patterns will enable DT&E and OT&E personnel to leverage their testing efforts with information provided by fleet users. Also DT&E and OT&E efforts would be more responsive to fleet issues as system deficiencies are identified and workarounds or updates are developed sooner. This enhancement of current product life cycles will facilitate better communication and requirements refinement between warfighters and acquisition personnel.

Perpetual Test and Evaluation

Operational weapons feedback could support the evolution of integrated developmental and operational test (IT&E) to perpetual test and evaluation where systems are tested throughout their life cycle by operational users in training and combat environments. In the 23 November edition of *Defense News*, the Director of Defense Research and Engineering for DoD, Zachary Lemnios, said that the military will "fight with prototypes"[27] in order to integrate combat experience into weapons upgrades. Mr Lemnios was commenting on ways to reduce cost and field arms faster. Weapons that support this paradigm will enable faster sharing of data pertinent to combat employment and training efforts.

Operational weapons feedback will mean that once a weapon system is fielded the test and evaluation process is not terminated for that particular build, block, version, and so forth. The systems will now support evaluation efforts vis-à-vis actual operational use and operational environments. A greater number of users will be able to evaluate tactics, techniques, and procedures in comparison with current capabilities. System and procedures development efforts will be expanded across a greater range of users—in essence perpetual testing.

Weapons Development *Feedforward*

While fighting with prototypes and perpetual testing will enable feedback into upgrades and improvement of existing weapons, the data gathered, organized, and archived from operational use (in conjunction with DT&E and OT&E data) could be used to feed forward into new weapons design and development programs. When requirements for future capabilities are developed, the data from operational weapons feedback can support priority and decision recommendations. Archived data of prior systems can be tabulated in a format that highlights current systems and capabilities gaps or limitations. This process is currently conducted; however, computer models, flight test data, and limited operational data are currently compiled.

Information on employment limitations, actual usage versus planned usage, air-to-air weapons features that aircrew would like to see in air-to-ground weapons and vice versa, launch-to-eject dynamics modeling, sky and ground background clutter data, and a whole host of other types of pertinent information could be gathered quickly across a range of weapons types and may be useful to weapons designers of future weapons (within proprietary and security constraints). Adding actual use trends, issues, and analysis would enhance the current requirements generations process supporting the design and development of new weapon systems. *Feedforward* is an added benefit of operational weapons feedback and the automated information exchange infrastructure to support it.

The combination of current test and evaluation practices with the added systems optimization capability of operational weapons feedback will enable the ability to perpetually test systems. The added weapons feedback and automation of data acquisition and analysis will enable feedforward into design, development, and improvement efforts. The improved communications, reduced data gaps, and automation decision support processes will support integrated design, development, and deployment (ID^3).

Barriers

In trying to reach this state of continuous product and process improvement there are multifaceted barriers. While specific technologies are the primary focus of this article, the abilities to sense, record, store, and transmit data are the areas where we have made the most progress in legacy weapons development. The disparate technologies required to support operational weapons feedback exist or are being developed. The processes and standards to do so are where we are lacking. While some of these

technologies are not very complicated, understanding what they can provide and how best to use and categorize these capabilities are questions we need to answer. Our ability to sense the world around us and gather reams of data is not the challenge; our challenge is to find better ways to store and share data and knowledge. DoD needs to better understand and invest more in data mining and knowledge discovery (the ability to glean information and knowledge from large quantities of data). As bandwidth and computing process continue to advance the prospects for larger and larger databases is a reality. Storing and managing data are equal to if not more significant than using the data.

Standards are another barrier to successful integration of operational weapons feedback. In the DoD's first network-enabled weapons, the JSOW C-1, the architecture was designed to maximize accountability and security, which detracted from flexibility and speed. The architecture was well thought out, but it was created by engineers and not by warfighters. The architecture development process requires technical specialists as well as operational specialists. Standards provide a way of ensuring interoperability and repeatability. The Link-16 message format is a NATO standard, however, the displayed Link-16 information in an F/A-18 Hornet is quite different from that in the F-16 Falcon. Standards need to be flexible, but they need to be comprehensive and cover what is important. The Bluetooth and the 802.11 standards have created a networking capability for consumer use that is robust, securable, and user friendly. While our security requirements can be a limiting factor, we can have this same success with military standards if we have the right people involved.

People are the principle reason for the integration of the technologies in this report. A significant barrier to operational weapons feedback resides in people. Addressing these issues requires an understanding of the integrated nature of the problem and associated opportunities. Educating operators, businessmen, and supporters about future technology and business processes will be essential to making headway. Again, the purpose of these technologies is to enable better decisions by humans. The nature of the changes inherent in the aforementioned processes requires looking at the technologies in a holistic sense and not in terms of bandwidth, processing power, or even electrical engineering or computer science. The feedback problem is an enterprise wide issue that can only be addressed in a systematic approach. According to Mr Tom Dabney of the Joint Strike Fighter Program Office, "achieving our vision involves multiple disciplines and a high degree of integration … that have to work towards a *common true north*…single program/service cannot effectively achieve [the] vision alone."[28] While Mr Dabney was speaking on operational health and decision support, the vision applies across a range of DoD weapons systems. The challenges are DoD wide, but so are the opportunities.

Conclusions and Recommendations

Keep on the lookout for novel ideas that others have used successfully. Your idea has to be original only in its adaptation to the problem you're working on.

–Thomas Edison

Conclusions

Future operational use of weapons information storage and communication technologies will provide weapons developers and users with required information to create and improve weapon systems and tactics. The focus of this article was to identify technologies and processes that support the future of DoD's evolutionary weapons system acquisition process. The premise of this article is that operational weapons need automated data acquisition technologies in addition to the current trend in network-enabled functionality to reduce time in designing, developing, deploying, and improving future weapons systems. A similar case was evident with the trends in precision timing and navigation hardware and software systems which resulted in global positioning system (GPS) receivers in many weapons and commercial applications. As the cost of computing, storage, and information communications hardware becomes more acceptable, future manufacturing technology will enable the integration of these technologies into network-enabled weapons. This will allow flight-test-like data to be gathered from weapons that are deployed operationally, where most weapons spend a majority of the life cycle.

Operational weapons feedback will enable the next generation of networked weapons to process, store, and transmit data for acquisition professionals and operators to use in the design, development, deployment, and improvement of relevant weapons programs and procedures. When combined with current acquisition practices this will reduce the time required and cost incurred to develop and improve future weapons systems. Operational weapons feedback will also enable users to develop tactics that reflect actual capabilities of current weapons by providing timely access to system performance in operationally representative or actual operational environments.

Operational weapons feedback could improve the information flow between users, developers, and maintainers. Synthesis of these technologies and processes will allow weapons systems to evolve into a feedback mechanism to the development and improvement process by gathering, communicating, and archiving information that is tailored to the stakeholders' needs. It can also potentially reduce data requirements as better information is provided via automated processing and analysis.

Smaller, faster, and cheaper computing enables systems to be embedded with processors that make networking, automation, feedback, and actuation possible. The miniaturization of the GPS receiver enabled the synthesis into what we refer to as a *smart weapon*. Smart systems, however, combine communications, control, and decision modeling technologies into systems that have sensory, calculative, and active or reactive capability. In a paper published by a Japanese research group, they collate research on an aircraft fuselage that was developed using smart sensors and materials. The fuselage was able to sense impacts, determine fuselage damage, and suppress damage "using embedded shape memory alloy films."[29] Technologies and concepts of operations like these have the potential to develop our current smart weapons into intelligent integrated network systems. Current precision location and identification capability will be augmented by the abilities to impact decisionmaking (targeting) by monitoring system health; detecting faults and taking or recommending action to the human-in-the-loop; providing imagery; predicting conflicts in space, time, and the

electromagnetic spectrum; providing feedback on employment and resulting damage; and other unforeseen uses.

Better Weapons Systems and Tactics

Operational weapons feedback will not only enable the development and improvement of weapon systems, but logistics support, training systems, and tactics. Instead of stand-alone weapons, or even network-enabled weapons, future weapons systems must be able to become a part of the interactions that are facilitated by designers, developers, testers, users, and program managers. Operational and training usage of weapons provides a wealth of data that could be automatically and expeditiously fed back into weapons improvement efforts. In referencing JSF's "undue concurrency of development, test, and production activities and the heightened risks it poses to achieving good cost, schedule, and performance outcomes,"[30] weapons systems based on the future of information communications and computing trends provide a way to mitigate this risk for future acquisitions by reducing time and increasing quality of data sharing among stakeholders. While the risk may still be high for a new development, operational weapons feedback will reduce technical risk over the life cycle of a weapon system.

According to warfare scholar Barry Watts in the *Air and Space Power Journal* article "Doctrine, Technology, and War," "getting doctrine wrong can lead to military disaster …superior technology in and of itself does not, and cannot, guarantee military success …technical feasibility is not equivalent to operational utility …and, finally, old doctrine seldom makes the most of new hardware."[31] While the nature of the relationship between doctrine, technology, and war has long been the subject of warfare studies dialogue, for this analysis the important fact is that they are related. Finding ways to improve connectivity and reap the benefits of this relationship between technology, doctrine, and war is in our best interest. Referencing the notional product lifecycle, operational weapons feedback shrinks the entire life cycle into a networked process characterized by the automated and expeditious flow of specified information. Imagine that each arrow touches the preceding and succeeding arrows, as well as being closer to, or even touching others around the circle. In reference to the relationship of technology, doctrine, and war Mr Watts concludes, "[t]he larger lesson is clear. Technology is important, but so is doctrine. Even more important is a harmonious fit between the two."[32] Operational weapons feedback is a technological mediator between technology, doctrine, and war.

As the acquisition process, policy, and technologies are changing it is up to DoD to redefine where it wants to go. If the doctrinal answer is still network-enabled warfare, then we need to ensure that information communications and computing capabilities are being exploited in a manner which will support shortening the time between the conceptualization and fielding of viable, effective, and suitable weapons and associated employment methods. Operational weapons feedback can help shorten this process.

Recommendations

DoD should integrate data acquisition and analysis capabilities into future weapons systems concepts. DoD should also develop architectures, processes, and infrastructure to support automated data acquisition and analysis of operational weapons feedback. The reason to integrate these technologies and processes is to support human assessment and decisionmaking. Technologies like integrated Network Enhanced Telemetry (iNET); Link-16; Joint Strike Fighter, Prognostics and Health Management (PHM) System; and the In-flight Data Acquisition Pod (I-DAP) should be analyzed for broader application in the DoD weapons portfolio. Also, processes and support systems such as the Joint Strike Fighter, Autonomic Logistic Information System (ALIS); and the Telemetry Network System should be expanded or mimicked in support of weapons systems.

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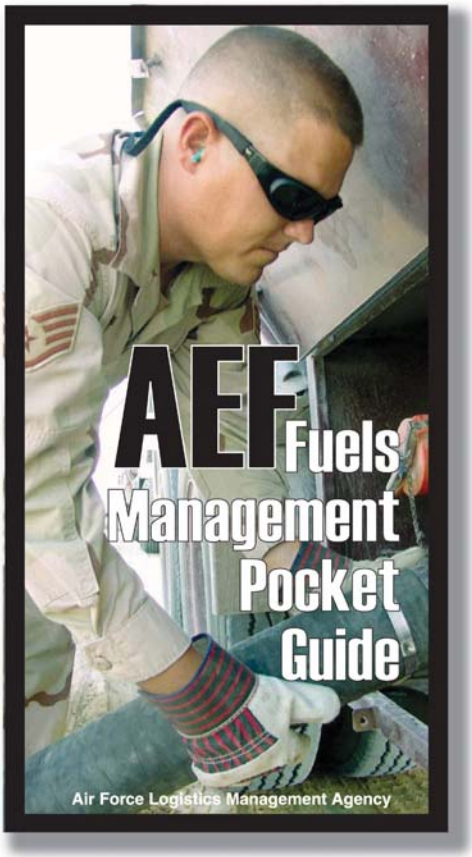

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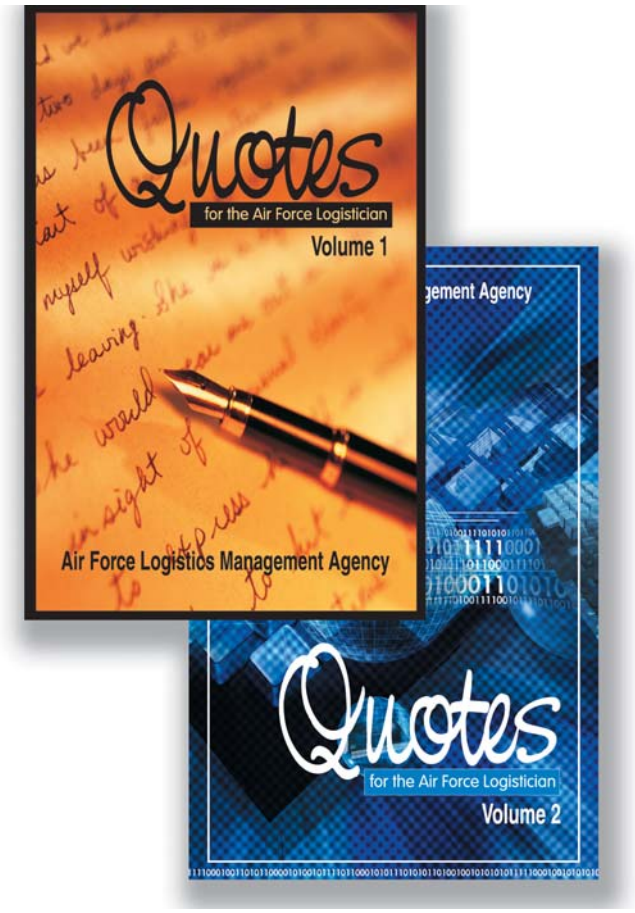

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