Men of Nottinghamshire and Derbyshire Regiment (The Sherwood Foresters) marching along Amiens-St. Quentin Road, from Foucancourt, near Brie, Somme, March 1917, after German withdrawal to Hindenburg Line (Courtesy Imperial War Museum/Ernest Brooks)

Accelerating Adaptation on the Western Front and Today

By Justin Lynch

In wars, militaries rarely start out perfectly suited for the challenges they will encounter. Their organization, tactics, and weapons are not optimally matched to their environment or their enemies. The ability to adapt more quickly than an adversary gives a force a significant advantage.[1] The growing role software plays in military technology could augment the speed of adaptation, but to capture such advantages, the joint force must invest in its digital workforce and infrastructure.

Adaptation in Warfare

Williamson Murray's *Military Adaptation in War* opens by stating that "adaptation in war represents one of the most persistent, yet rarely examined problems that military institutions confront" and

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that "one of the foremost attributes of military effectiveness must lie in the ability of armies, navies, or air forces to recognize and adapt to the actual conditions of combat."[2] A short study of warfare on the Western Front during World War I showcases adaptation's importance. After the emergence of trench warfare, both sides quickly began adjusting their technology, tactics, and organizations in an attempt to achieve an operational breakthrough. The result was a race between combatants to adapt faster than their adversaries.

World War I

In summer 1914, young men across Europe marched to war. They left for what most of them believed would be a short conflict, one decided by the power of the offensive. After 4 months, they had settled into trench warfare that bore little resemblance to the war they had prepared for. Four long years later, the war on the Western Front bore even less resemblance to the vision held before August 1914.

Before combat began, military leaders understood that war was changing. A great deal of new military technology—such as scientific artillery, the machine gun, motor vehicles, and barbed wire—had developed in the years before 1914. Military leaders had already seen some of these tools in action, but few realized the nature or the magnitude of the impact that increased firepower would have on warfare between peer adversaries.[3] Moreover, because the combatants did not understand the effects new weapons would have, military tactics had barely changed since the 19th century.[4]

War of Maneuver. After hostilities began, the Germans and the French sought to destroy each other's armies via maneuver at the operational level.[5] Neither side had prepared for the newly increased firepower, and so they had disorganized maneuver and indecisive results rather than the power of the offense. As a result, the war quickly began to transition away from operational maneuver. At the end of August 1914, casualties were high, but the war was still one of maneuver. By September, the Germans were establishing trenches with interlocking fields of machine-gun fire on the Aisne. By October, disorganized maneuver had begun changing into a form of mutual siege warfare. By November, trench warfare prevented either side from achieving a decisive victory using any previous tactics, and thus forced a strategic stalemate.[6]

Trench Warfare and the Race to Adapt. Historians and artists often depict trench warfare as a static struggle characterized by incompetent leaders who ordered hopeless attack after hopeless attack in pursuit of the white whale of operational breakthrough.[7] Although not entirely untrue, that narrative captures only a sliver of reality. The challenges of trench warfare prevented both sides from breaking through and defeating the enemy. Both sides looked to a combination of technological and operational adaptation to solve this problem. Rather than just a static war, the Western Front was a competition to see which side could adapt its organizations and tactics, create new weapons for trench warfare, and react to adversary adaptations quickly enough to seize an advantage.[8]

The advent of commercial dual-use technology played a particularly prominent role. Much like today, technology development in the early 20th century took place largely in the private sector. Private-sector companies created aircraft, motorized vehicles, and other dual-use technology that became significant during World War I. Military leaders were aware that emerging civilian technology with potential military applications in communications, aircraft, and mechanized vehicles was mature enough to quickly prototype; when the war began, they began adapting technology to try to overcome the new challenges found on the Western Front.

For the infantry, trenches and other fortifications drove a shift from maneuver to mass. Continuous layered trench lines eliminated exposed flanks and forced units to rely more on frontal assaults driven by mass. To build mass, both sides began expanding their logistics infrastructure. Stable fronts allowed participants to build roads up to their trench systems and to increasingly use motorized transports to move troops, supplies, and equipment. The French used 600 Renault taxis to move 3,000 soldiers to the First Battle of the Marne in the world's first motorized military convoy in 1914.[9] By 1916, the French had transported 180,000 metric tons and 300,000 men by vehicle.[10] The improvement in logistics infrastructure, however, largely stopped behind the front. Units assaulting across no-man's-land still did not have the logistic tail needed to sustain their attack and break the stalemate.[11]

Mechanization offered a potential solution. Mechanized forces grew out of the belief that armies could use tractor technology to cross muddy terrain and survive enemy fires. Great Britain's War Office largely ignored tractor technology's potential in 1914. But that eventually changed, and the British used tanks in combat for the first time on September 15, 1916, at Flers.[12] The attack failed to create the hoped-for breakthrough, but it did teach the British important lessons about tank construction and employment. (The French faced a similar course.) By 1917, however, tanks were a major component of British offenses. Tanks, properly armed and armored, could escort infantry formations into trench systems and reduce sustainment issues by carrying water and ammunition.

The role of aircraft also changed. Before the war, military theorists believed aircraft would serve primarily as reconnaissance and artillery spotters. But once the war started, new roles emerged. Air warfare quickly grew into a fight for air superiority. Initially, air combat was fought between individuals. By late 1917, mass formations had reduced the role of individual aerial duels, and the ability of each state's industrial base to produce aircraft was as important as the courage of individual pilots.[13] Air warfare also expanded to include close air support and eventually into the bombing of cities such as Liège, Paris, and London.[14]

Militaries improved their growing air forces in two ways. They competed to develop a combination of doctrine and training that would allow them to achieve

Gun crew from Regimental Headquarters Company, 23rd Infantry, firing 37-millimeter gun during advance against German entrenched positions during Meuse-Argonne offensive, September 26–November 11, 1918 (U.S. Army/National Archives and Records Administration)

air superiority and deliver effects. Aircraft technology also changed quickly: The final report of the Chief of the Air Service at the end of the war claimed that "the improvement in pursuit airplanes was so rapid that few types retained their superiority for more than six months."[15]

The New Armies. By late 1917, the contest to adapt to trench warfare had caused both the Germans and the Triple Entente to develop new types of armies: the German coordination-of-arms model and the Entente tank-army model. The former, a combined arms force, relied on an unprecedented coordination of aircraft, artillery, and shock troops to create and exploit breakthroughs. It included improved small arms, aircraft, and artillery but relied noticeably less on technological solutions than the tank-army model. The tank-army model relied predominantly on the tank to help infantries cross no-man's-land. At the Battle of Cambrai in November and December of 1917, the British sent 450 tanks followed by 6 infantry divisions across a dry, flat section of the Western Front—and was able to advance 7 kilometers. Though the attack failed, by 1918, tanks backed by massed infantry and supported by artillery and aircraft contributed heavily to allied breakthroughs. German leaders coined the term *Panzerschreck* (tank fright) to describe the mass fear that tank formations inspired.[16]

The new armies constituted a major innovation. They created new tactical and operational concepts, trained their soldiers to fight in a new way, and integrated civilian technology—all of which resulted in forces that were more tightly coordinated than previous military forces and that applied firepower more effectively. The biggest changes to warfare, however, came from the role of tanks and aircraft. Mechanization gave maneuver forces new mobility, survivability, and firepower. Airpower expanded war from the land and sea to the air. Tanks and aircraft fundamentally changed the context within which wars were fought and showed the power of integrating emerging technology and tactics. By comparison, the coordination-of-arms model's failure to accomplish its strategic objectives showed the cost of an inadequate response to new operational challenges.

The Scale of Change. The states and armies that fought World War I underwent massive changes. The introduction of dual-use technology allowed both sides to quickly introduce new weapons. The generals who led these armies found themselves unprepared for the type of warfare they would fight; however, contrary to widespread belief, this lack of preparation was due more to their quickly changing circumstances than to incompetence. Instead of fighting the war they had prepared for, generals found themselves struggling to understand how combat had changed from operational maneuver to trench warfare—and then how to alter it yet again to achieve decisive victories.[17]

As a result, the armies that marched off to battle in the summer of 1914 would barely have recognized the type of warfare they would fight by the summer of 1917. The Hindenburg Line's fate illustrates the rate of change on the Western Front. When it was built in 1916, circumstances had changed, and it was one of the strongest, most advanced defensive positions in Western Europe; by the time allied forces reached it in 1918, it was obsolete.[18]

The Present

Militaries will undoubtedly face new and sometimes unexpected operational challenges—and to overcome them, they will need to adapt their doctrine, organizational structure, training, and technology. Although no one can predict the future, practitioners should use history to drive their inquiry and to understand how to question their assumptions.[19]

What Is the Likely Role of Dual-Use Technology Today? There is every reason to believe that adaptation will continue to play a role in conflict. It is also likely that, much like during World War I, dual-use technology will be adapted for combat. Since the end of the Cold War, the U.S. research and development base has shifted from the government to the private sector. Commercial firms develop most new technologies, including those with possible military application.[20] The private sector, including businesses that do not usually work with the military, leads the development of autonomous systems, machine learning, software, heavy equipment manufacturing and repair, biotechnology, and other potential dual-use technologies at a faster rate than does the Department of Defense (DOD).[21] If DOD and its foreign counterparts attempt to adapt dual-use technology themselves—or turn to the private sector and ask it to do so for the sake of nationalism and profit—it is highly probable they will be able to quickly weaponize existing technology that is not already in military use. The result is a situation in which states that can more quickly adopt dual-use technology and integrate it into their tactics and strategy will have the advantage.

How Will Changes in Technology Affect Adaptation? Although the summer of 1914 and the present day have some things in common, there are key differences. The most significant is the increasingly important role software plays in society and warfare. Digital systems have become integral to most economies, infrastructure, and social systems. Many militaries, particularly the U.S. military, have become more and more digitized—and therefore reliant on their software's performance. Eric Schmidt, former chief executive officer of Alphabet and chair of both the Defense Innovation Board and the National Security Commission on Artificial Intelligence, refers to the current day as the age of software supremacy.[22] Software can change the capabilities of hardware without changing its physical features. Examples include network updates that reduce vulnerabilities and improve intrusion and anomaly detection, improvements to algorithms that control tracking systems, and changes to data management systems that allow warfighters to communicate faster and more efficiently. Other examples will soon include improvements to autonomous systems that will perform a significant role in actual combat.[23]

Software's role in conflict has already been demonstrated, particularly during attacks on digital systems. Some network breaches—such as Stuxnet and the various and frequent hacks by state actors of one another's public and private systems—have made headlines.[24] In 2017, the U.S. military tested its ability to stop armored vehicles using computer network attacks, but it has not publicly explored that capability's limitations or potential in combat.[25]

One implication of software's increasing significance is that tactical adaptation will begin to include—and, in some circumstances, require—software changes. If future conflicts see a software-driven race to adapt similar to the race on the Western Front, then adversaries will change their platforms to perform better in the environment and against their foes. Weapons guidance systems will need to better track adversaries using new camouflage, control systems will need to respond faster, electronic warfare platforms will need to better infiltrate enemy systems, and possible autonomous weapons systems will need to better locate and attack their targets.

Software's Acceleration of Adaptation

One of the biggest discontinuities between today's software and the types of technology adapted during World War I is that engineers can develop new software more quickly than they can new hardware. Software development relies on programming instead of manufacturing processes, allowing updates to bypass some of the physical constraints that slow down hardware development. Engineers can create new programs as quickly as they can type code and verify its functionality.

Once completed, software changes can also be implemented faster than hardware updates. New programs and updates can spread across the joint force as quickly and as broadly as an email, then install in seconds or minutes. It takes far less time to download a software update on a desktop computer than it does to fly or ship heavy equipment from the United States to an overseas theater.

Overall, software's increasing importance for military operations, pace of development, and speed of delivery will accelerate the rate of technology adaptation in warfare. Imagine weapon adaptation taking place at the rate Silicon Valley can produce new software updates—instead of the rate at which factories could produce and deliver new hardware in 1918. In 1918, a ship departing the East Coast for a combat zone arrived in the same state, with the same capabilities, as when it departed. Today, a ship leaving the East Coast that receives software updates to its communication systems, targeting software, and the programs controlling its automatic and autonomous systems can have different capabilities when it arrives in theater; this will only be truer tomorrow.

Recommendations

The joint force should establish rapid development and acquisition capabilities that can help commands quickly react to a changing threat environment, spot opportunities, and create the hardware and software that warfighters need to defeat their adversaries. Although this focuses on the production and use of digital technology, the biggest changes to the joint force will need to be in its investments in human capital and organizational structure.

Public-Private Partnerships. The most commonly discussed solution to military innovation challenges is to establish stronger public-private partnerships. DOD already has several programs in place to improve its relationship with private-sector developers or to solve specific problems.[26] Although these programs address important issues, improving public-private partnerships alone will not solve the challenges described herein. The current DOD relationship with the private sector has several challenges. These include a labyrinthine contracting process, cultural differences between the military and startup communities, and the DOD focus on long procurement cycles.[27] It is also difficult to predict how organizations that justifiably view themselves as global companies will respond to war.[28]

Personnel. Instead of relying primarily on the private sector, DOD should grow its own software development capabilities. Stephen Peter Rosen argues that "peacetime innovation has been possible when senior military officers, reacting not to intelligence about the enemy but to a structural change in the security

U.S. Soldiers of 30th Infantry Division with German prisoners following capture of Bellicourt, France, after Battle of St. Quentin Canal, September 29, 1918 (Courtesy Imperial War Museum/David McLellan)

environment, have acted to create a new promotion pathway for junior officers practicing a new way of war."[29] To create the ability to adapt software to rapidly changing circumstances, DOD must have highly skilled military and civilian personnel who provide three things:

- a centralized group of experts that can create high-quality software and algorithms and control their quality
- personnel distributed to tactical units who can recognize new challenges and opportunities and create early versions of new software
- the ability to quickly build and update networks for new capabilities.

These proficiencies are different from those of U.S. Cyber Command, whose focus is on "defending the DODIN [DOD information networks], providing support to combatant commanders for execution of their missions around the world, and strengthening our nation's ability to withstand and respond to cyber attack."[30] Though critical, that mission focuses more on the defense, exploitation, and attack of networks than on the creation of new software.

To meet these needs, each branch of the military requires its own software developers. Rapidly identifying opportunities and creating software to exploit them will be a form of maneuver just as critical as performing fleet movements, flying aircraft, or plotting ground forces. Because the Services would be extremely reluctant to rely on outside sources to perform these roles, they should treat software development with the same degree of concern. Parts of the military—such as U.S. Special Operations Command, the Air Force's Kessel Run, and the Army's Software Factory—have made a start, but the military needs more software developers in more units.[31]

Code and Data Access. Once in place, software developers require architecture and authorizations that allow them to locally manage, build, review, test, and release code. The Defense Innovation Board Software Acquisition and Practices study recommends managing source code in a single repository but encourages engineers to fix problems "independent of program boundaries."[32] For engineers to manage, build, debug, and release new software, they need access to their systems' codes, the authorization to change them, and the ability to disseminate changes.

Access to data will also be crucial. Data helps software developers understand system requirements. Machine learning in particular requires access to large data sets. Training and retraining algorithms to address new challenges will often require access to data sets from units encountering the challenge. To meet this requirement, tactical units need the bandwidth, computing power, software tools, and training to share and process large data sets. To be clear, this architecture, authorization, and access to data are not intended to create new technology; they are necessary to allow DOD to use existing technology effectively.

Organizational Structure. As it acknowledges the need to quickly create software for tactical environments, the joint force must determine where in its organizational structure it should place its developers and their tools. The degree to which software development and adaptation is centralized should be a function of both the consequences of errors and the consequences of adapting slowly. Systems with little margin for error that do not need to change quickly, such as aircraft carrier preventive maintenance, should be tightly controlled at a centralized facility where maintenance and development experts can methodically control quality. Other capabilities have a wider margin for error and require more rapid, localized adaptation. Units in ground combat have fewer systems that can produce catastrophic failures, and these units often experience stark differences in their operating environment; they may have to operate with limited bandwidth to their higher headquarters. In these circumstances, decentralized adaptation—and, in some cases, even decentralized development—may be more appropriate.

Some traditional private-sector companies that have integrated artificial intelligence and other modern software development processes have benefited from implementing a hub-and-spoke model. Generally, the hub, or central facility, is responsible for the training, education, and management of experts, some research and development, and the development and promulgation of standards. Spokes, or decentralized teams that reside within other programs, identify and exploit local opportunities, all while sending updates to the hub. In the joint force, hubs could exist in unified commands or centers of excellence. Spokes would exist in tactical- and operational-level units.[33]

Changing organizational structure does more than concentrate talent, training, and authorities; it is also an important part of building bureaucracy that supports rather than constrains new organizational processes. Barry Watts and Williamson Murray speak to the "unavoidable necessity of bureaucratic acceptance to successful peacetime innovation. . . . Without the emergence of bureaucratic acceptance by senior military leaders, including adequate funding for new enterprises and viable career paths to attract bright officers, it is difficult, if not impossible, for new ways of fighting to take root within existing military institutions."[34] Organizational structures such as a hub-and-spoke system help incentivize bureaucratic acceptance by senior leaders serving in the hub, channel funding into necessary programs, and constitute one of the best ways to establish viable career paths.

Given the rapidly changing state of both civilian and military technology, the next war's initial salvos will likely include weapons never before fired in anger—and whose combined effect on warfare is difficult to predict. If the conflict lasts very long, it will shift into a race to adapt to those effects and gain a competitive edge in the new operational environment. Military and civilian innovators will quickly repurpose civilian technology for military use. The state that wins the race may win the war. If the United States wants to prevail, it needs to develop the ability to quickly identify challenges and opportunities, and then field new technology to meet them. **JFQ**

Notes

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