THE LAND WARFARE PAPERS

No. 87 MARCH 2012

Historical Lessons Applied to the Current Technical Revolution in Military Affairs

Benjamin Huebschman

A National Security Affairs Paper
published on occasion by
THE INSTITUTE OF LAND WARFARE
ASSOCIATION OF THE UNITED STATES ARMY
Arlington, Virginia

Historical Lessons Applied to the Current Technical Revolution in Military Affairs

by

Benjamin Huebschman

The Institute of Land Warfare
ASSOCIATION OF THE UNITED STATES ARMY

AN INSTITUTE OF LAND WARFARE PAPER

The purpose of the Institute of Land Warfare is to extend the educational work of AUSA by sponsoring scholarly publications, to include books, monographs and essays on key defense issues, as well as workshops and symposia. A work selected for publication as a Land Warfare Paper represents research by the author which, in the opinion of ILW's editorial board, will contribute to a better understanding of a particular defense or national security issue. Publication as an Institute of Land Warfare Paper does not indicate that the Association of the United States Army agrees with everything in the paper but does suggest that the Association believes the paper will stimulate the thinking of AUSA members and others concerned about important defense issues.

LAND WARFARE PAPER NO. 87, March 2012

Historical Lessons Applied to the Current Technical Revolution in Military Affairs

by Benjamin Huebschman

Major Benjamin D. Huebschman, U.S. Army Reserve, is a research engineer with an extensive military background in Field Artillery, Military Intelligence and Psychological Operations. He is currently serving on active duty at the U.S. Army Intelligence and Security Command as the Chief of Operations for the Futures Directorate. Prior to this assignment, he was an electronics engineer at the U.S. Army Research Laboratory, where he authored several peer-reviewed scientific and engineering articles. His military career has seen deployments in the Balkan Peninsula, where he served in a peacekeeping role. He also deployed to the Middle East where he served as the chief psychological operations officer to the U.S. Central Command Air Forces during the invasion of Iraq. MAJ Huebschman received a Bachelor's Degree in electrical engineering from Purdue University and a Master's Degree and Ph.D., also in electrical engineering, from the University of Maryland.

Inquiries regarding this and future Land Warfare Papers should be directed to: AUSA's Institute of Land Warfare, Attn: Director, ILW Programs, 2425 Wilson Boulevard, Arlington VA 22201, e-mail *sdaugherty@ausa.org* or telephone (direct dial) 703-907-2627 or (toll free) 1-800-336-4570, ext. 2627.

Contents

Foreword

American battlefield supremacy has forced the adversary to adopt an asymmetric approach to warfare. Capital-intensive warfare has focused on the larger weapon systems, but the weapons used to equip the dismounted ground Soldier have remained largely static—despite ten years of war against insurgents who have relied on the asymmetric fight. To combat this threat, the Army is in need of technology that can transfer battlefield supremacy down to the level of the individual ground Soldier. In this paper, the author explains that hastening the integration of automation technologies with military equipment provides unprecedented degrees of freedom in system development.

The development of future weapon systems, including those used by the dismounted Soldier, benefits from a review of the evolution of weapons. With that in mind, the author presents the key stages in the development of weapon systems as case studies, examining each stage with sufficient detail and in its historical context. Each case study provides lessons that can then be applied to modern weapon development. The author's analysis of these case studies leads him to propose an instantiation of a modern system with regard to Battlefield Operating Systems.

Gordon R. Sullivan
General, U.S. Army Retired
President, Association of the United States Army

14 March 2012

Historical Lessons Applied to the Current Technical Revolution in Military Affairs

Introduction

Army and Marine Corps platoons and squads have borne the wars' burdens in Iraq and Afghanistan.

Sandra I. Erwin[1]

Despite the persistent counterinsurgency that the United States has been waging for the past decade, the technology available to American ground Soldiers is remarkably similar to the technology that was available to them at the beginning of the conflict. The military stands on the edge of the next revolution in military affairs. Advances in automation and information technologies have dramatically transformed many aspects of civilian society in the past 20 years. When compared to this frenzy of technological development, especially in consumer electronics, these advances have entered military technology at a deliberate and gradual pace.

Western warfare in general and American warfare specifically have always been capital-intensive endeavors. Major capital systems such as air-superiority fighter aircraft and main battle tanks have established a degree of supremacy in technological improvement. This supremacy in weapons traditionally has been considered to be of strategic significance to U.S. interests. However, given the strategic nature of American casualties in recent conflicts, a major upgrade in the military capabilities of dismounted Soldiers is critical to U.S. strategy in the protracted counterinsurgency fight. While the United States may want its adversaries to attempt to counter U.S. asymmetric superiority in technology and training with a symmetric response, once American superiority becomes manifestly and painfully obvious to the enemy, it is reasonable to assume that he will resort to asymmetric tactics and technology to accomplish his objectives.

Part of the response to an asymmetric threat is to oppose violently the asymmetric warrior. Denying insurgents the ability to act directly erodes their resource base and credibility as an effective fighting force. The enemy may not be as sensitive as the American populace to its number of casualties, but after a certain level of enemy casualties is reached, support for direct attacks against U.S. Soldiers begins to collapse, prompting the adoption of other tactics or a waning of the insurgency. While a comprehensive counterinsurgency strategy has been discussed at length in other documents,[2] it is beyond the scope of this paper. Here, counterinsurgency strategy will be confined to the assertion that one of the requirements to defeat an insurgency is to do so on the battlefield, taking advantage of every opportunity. To seize and maintain the initiative in an asymmetric conflict is difficult and sometimes impossible. Without the initiative, it is necessary—at least on occasion—to let the enemy set the operational tempo. Mass can be achieved through the use of increased numbers of dismounted Soldiers. However, it is often prohibitively expensive for a sustained effort, and a concentration of Soldiers is vulnerable to area-effect weapons such as mortar fire and prepositioned explosives. A concerted effort is required to provide battlefield dominance to the infantry Soldier through the same quality of technical superiority that has led to dominance in air and armored combat.

To improve technologies available to Soldiers, it is first necessary to understand the current state of the art. As a testament to the maturity of firearms, the weapons with which the United States equips its Soldiers are only marginally superior to those used 100 years earlier. Among some Afghan tribes, the Enfield .303 enjoys a reputation superior to that of the AK-47;[3] Soldiers who stormed up San Juan Hill in 1898 carried rifles whose range and muzzle velocity were comparable to those of weapons carried by Soldiers today. That said, U.S. Soldiers have the advantage over their predecessors in training, communications and the ability to bring the fires of more sophisticated weapon systems down on their adversaries. Direct capital expenditure on the improvement of dismounted infantry Soldier performance and capabilities has relied until very recent times on increased training. While superior training can dramatically increase the battlefield effectiveness of a Soldier, it does not bring the same decisive psychological advantage as a heavy weapon system. The will and ability to consistently hit an enemy target at ranges in excess of 100 meters in battlefield conditions, to maneuver under fire and to close with the enemy in all weather conditions, even in darkness, might be decisive in a small-arms engagement. However, to the enemy the infantry Soldier appears to be armed with weapons of the same quality as those of his own fighters. From the perspective of the insurgents, it might appear that parity does exist.

The concept of dramatic change in the profession of arms was developed by Soviet military theorists and labeled "military-technical revolutions."[4] The term "revolution in military affairs" (RMA) was first coined by the U.S. Department of Defense's Office of Net Assessment in the 1980s and was expanded to include improvements in communication, tactics, logistics and social organizations. The requirement proposed by Williamson Murray and MacGregor Knox in their definitive book, *The Dynamics of Military Revolutions, 1300–2050*, will be applied to RMAs in this paper:

> Revolutions in military affairs require the assembly of a complex mix of tactical, organizational, doctrinal and technological innovations in order to implement a new conceptual approach to warfare or to a specialized sub-branch of warfare.[5]

One characteristic of an RMA is an asymmetric result from a symmetric confrontation, as seen in Germany's invasion of France in 1940 and the U.S. invasion of Iraq in 1991. During the invasion of France, the Allies enjoyed technological and numerical parity with the Germans. The Germans, however, were able to defeat the Allies with relatively few casualties through their use of *Blitzkrieg*, an innovated maneuver warfare doctrine based on agility and their integration of the effects of air and artillery with ground attacks by massed armor; this is now known as "combined-arms tactics." During the 1991 Gulf War, technical superiority, better training and a sound tactical doctrine produced a swift victory of the coalition ground forces following a successful air campaign.

The life cycle of a technical RMA begins when one nation or faction develops a new technology. Early adopters of an RMA may benefit from acquiring the technology that constitutes the RMA. If the advantages are apparent, others will develop the technology, and all military entities will attempt to improve the weapon system. The cost of capital-intensive warfare in the modern age may prove prohibitive, because only a handful of wealthy nation states or alliances can field these modern systems. However, this outcome is not certain. Proliferation of low-cost, high-quality computational electronics and tools for automation, when combined with a development process that is open source or adapted from dual-use technologies, could put futuristic weapon systems into the hands of operators with very limited resources.

Marginal and evolutionary increases in weapon capabilities are not considered RMAs. If a new fighter aircraft has an extended cruising range and a slight advantage in aerial combat, it probably does not constitute an RMA. On the other hand, if the fighter compels an adversary to send all his planes to safety in a remote location and to rely entirely on air defense artillery to defend his airspace, this may be considered an RMA. Tactical or organizational RMAs proliferate much more rapidly than technical RMAs. The tactics developed by the Germans and used against the Poles, French and Soviets early in World War II were the same tactics used against the Germans after their initial successes culminated. An RMA could be thought of as the technological and doctrinal equivalent of the initiative. An RMA would force the belligerent without the innovation to react to the early adopter. The new technology and tactics require the adversary who does not possess the same advantages to dramatically alter the way he wages war—by either mimicking the innovator or developing countermeasures. Without such alterations, the enemy is rapidly defeated.

The current technical RMA is based on the integration into major weapon systems of automation technologies provided by semiconductor integrated circuits. In addition, increases in both performance from better materials and complexity have allowed modern systems to enjoy the synergistic effect of improvements to component systems, which effectively constitutes an RMA. Technological examples of the current RMA include precision-guided weapon systems and weapons with computer-aided targeting integrated into their optical target acquisition components. Recently, projectiles that integrate global positioning system (GPS) guidance into their targeting in the terminal arc of their trajectories[6] or that are actually capable of acquiring and engaging a target during the terminal arc[7] simultaneously reduce both the collateral damage and the number of rounds required to achieve the desired effect. Fully automated systems such as the unmanned aerial systems (UAS) are being used for surveillance and as ground-attack aircraft against asymmetric opponents who lack advanced antiaircraft weapons. Automation has had the greatest difficulty in making progress in equipment used by light maneuver forces. Some remotely controlled unmanned ground systems (UGS) have augmented the capabilities of Soldiers, but the utility of these systems is limited when compared to aerial systems. The UGS that have been fielded are primarily being used to provide remote manipulation and to assess situations that are particularly threatening to Soldiers.[8] Some remotely controlled ground vehicles have weapons mounted on them, allowing Soldiers to operate them at a distance and under limited conditions.[9]

The next RMA will complete the saturation of the battlefield with integrated circuits, making information and automation abundant. It is reasonable to expect automated systems that are becoming more common in the air to become prolific on the ground as well. The form, shape, function and degree of autonomy will evolve with the technology and tactics of belligerents and potential belligerents. The complexity of land warfare explains why this is the area in which automation has been so slow to make progress. The difficulties in developing a fully automated ground system become apparent when compared with the aerial battle space. Once a vehicle is airborne, the sky contains either enemies (targets) and/or friendlies (obstacles), but mostly it contains just empty (unoccupied) space. The earliest automated aerial systems were missiles; simple cruise missiles were some of the first UAS. Developed as terror weapons during World War II, UAS were essentially planes with a rudimentary autopilot, packed with explosives almost accurate enough to hit a city.[10] The algorithms that control automated systems used in naval combat must be programmed to take into account the interface between sea and air. Since most naval systems can travel exclusively in the air, under the water or along the interface between air and water, the naval battlespace brings additional complexity to autonomous systems as weapons in one region attempt to engage those in another. Antiship remotely controlled glide bombs were used first by the Germans and later by the Americans in World War II.[11] In both the air and sea, most of the space in which a system can maneuver is free from natural and manmade obstacles. For ground-based systems, however, quite a different circumstance exists. Obstacles are the rule, and maneuver space is the exception. This concept is demonstrated by examining the distance that a ground vehicle travels before being required to alter direction to avoid an obstacle. In addition to the problem of maneuver space, there is a problem of perception. Concealment that obscures the maneuver space is much more abundant for ground systems.

Just as history is the laboratory of the social sciences, it is also the laboratory of armed conflict. The success or failure of a military philosophy or strategy can be proven by its historical performance. The same rules apply for the lessons of war and for the synergistic relationship between war and the tools used to wage it. If on the verge of a technological-based revolution in military affairs, previous case studies in fires, maneuver and weapons of mass destruction (WMDs) may reveal lessons that can help assess when they should be applied to the modern situation.

Case Study 1: Fires

God fights on the side with the best artillery.

Commonly attributed to Napoleon Bonaparte

Early in the 19th century cannons were made from either bronze or cast iron. Bronze was light, tough and expensive; iron was heavy and cheap. During this time, most mobile field guns were made of bronze while larger pieces, such as siege artillery and coastal batteries, were made of iron.[12] By the time of the American Civil War, improvements in the quality of material properties of iron had reached the point that large numbers of field guns were manufactured from iron. Although the bronze Napoleon 12-pounders were the most common cannon during the Civil War, the United States would never again use bronze cannon in war.[13] The Bessemer process eventually resulted in a sufficient quantity of steel at a price low enough to make it practical for the manufacturing of large weapons.

Improvements in material and manufacturing allowed for greater complexity in weapon design. For centuries, rifling had been used in small arms to stabilize projectiles.[14] It gained widespread use in muskets in the mid-19th century. Rifling on a barrel transfers a portion of the kinetic energy from the velocity of a round to its angular momentum. The design makes the projectile more stable and accurate, but this accuracy comes at the cost of muzzle velocity and range. For this reason, along with difficulties associated with manufacturing, rifled artillery in substantial quantities followed widespread use of rifled small arms by several decades. During the Civil War, the 3-inch ordnance rifle and other early smaller-caliber rifled artillery were used contemporaneously with larger-caliber smooth-bore artillery.[15]

Precision machining of large systems on an industrial scale allowed for additional innovation. Experimental small-caliber breech-loading rifled guns were produced in small quantities by the end of the Civil War, but the superiority of steel breech-loading rifled artillery was not proven until the Battle of Sedan in 1870.[16] The 80mm 4-pounder Krupp field guns used by Prussia, the leader of the North German Confederation, had superior range and rate of fire over the French adversaries, who relied on muzzle-loading artillery.[17] The next innovation in artillery was the development of a mechanism that absorbed recoil. With a recoil mechanism, an artillery piece could fire while remaining in battery. Prior to this invention, the recoil from each round would propel the gun out of position, and it would then have to be pushed back into place by the gunners. The first artillery piece to integrate a hydropneumatic recoil system was the French 75mm field gun, fielded in 1898.[18] This weapon was so advanced that it remained in use for more than 40 years. It also incorporated as propellant one of the new family of explosives that is collectively referred to as smokeless powder.

By the late 19th century all of the components for advanced artillery systems were in place. With the exception of mortars, rockets and missiles, all 20th century field artillery contained the features of the French 75mm field gun. The French 75mm and all subsequent field artillery comprise high-quality, steel-rifled barrels mounted onto systems for absorbing recoil and firing projectiles propelled by high explosive. This is not to say that artillery had ceased to change following the introduction of this piece. Rather, with all of the components fixed, the art of weapon design truly began. An analogy can be drawn between this period of weapon development and the Cambrian explosion of biological evolutionary history. Cambrian was a geological period that spanned seven million years and began 57 million years ago. The period saw unprecedented emergence of several phyla and many different animal forms as life spread, filling every biological niche.[19] It was a period of both rapid emergence of species and rapid extinction. By the end of the Cambrian period, only a few successful evolutionary phyla occupied much of the biosphere.[20]

In this analogy, the two evolutionary lines are competing for dominance; such competition is similar to that between field guns and howitzers in the artillery arena. Field guns are optically targeted, resulting in greater accuracy; they fire with a flat trajectory and greater muzzle velocity than howitzers. The high velocity and accurate fire allow for field guns to be used as kinetic-energy (KE) weapons in addition to delivering high-explosive (HE) rounds. Nevertheless, the advantages of howitzers far outweigh those of field guns. The howitzer fires in a high-ballistic trajectory. Because of the ballistic arc of the howitzer round, the howitzer gunner does not have to see the target to attack it. Thus, the space of the battlefield that can be engaged by the howitzer is largely determined by the range of the howitzer, while the amount of the battlefield that can be engaged by a field gun is determined by its field of view. The advantages of the howitzers are multiplied when considering the potential to mass fires. All howitzers that are capable of ranging a target can synchronize fire and mass on that target. To mass fire with field guns, it is necessary to collocate them in a single line so that all of them can actually see the target. Therefore, field guns were effective in the 19th century when the battlefield was essentially linear and small in scale. As the lethality and range of weapons increased, the size of the battlefield increased as well, and field guns became more vulnerable and less effective when compared with howitzers. Modern tube artillery pieces are technically described as gun-howitzers, because they are capable of operating in direct fire mode; however, using howitzers for direct fire is more common with emergency capabilities.

In addition to the technological ability to produce such weapons, the rapid development of fires required motivation and resources. Both were provided in ample supply during World War I. At the onset of the war, the French artillery consisted primarily of the French 75mm gun.[21] The French possessed heavy field howitzers at corps level, but initially these were not sufficient to be decisive.[22] The German artillery consisted of quick-firing light 77mm field guns, 105mm medium howitzers and 150mm heavy howitzers.[23] From an organizational perspective, this artillery was distributed between division and corps levels. In practice, all artillery was under the command of the division commander and his subordinates. It should be noted that the definitions of light, medium and heavy artillery shifted during this war. Prior to World War I, the 105mm howitzers were considered medium, the 150mm heavy. After the war, these same calibers were now light and medium, respectively. The increase in the size of the artillery at the top prompted this shift. In the first battles of World War I, the advantages of the howitzer, as previously described, were quite obvious. German guns were able to fire from defilade and mass against the French batteries, while the French were unable to return fire. As the invasion of France culminated and maneuver transitioned to stalemate, commanders sought technological solutions. Howitzer artillery was capable of reaching targets and soldiers in fortifications and trenches. The flat trajectory of field guns made them more accurate against vertical targets, but this apparent advantage actually made field guns less accurate against horizontal targets such as soldiers in trenches.

At the beginning of the conflict, defensive fortification, overhead cover and sheltered bunkers provided soldiers with adequate protection from most artillery fielded. The solution was larger artillery. Larger howitzers began to replace field guns; heavy artillery, previously seen only at the highest echelons, became much more common. Initially, the Germans were in a better position than the French because of their doctrinal preference for howitzers. Siege artillery was employed to punch through an adversary's defensive positions. At some point, increasing the size of artillery resulted in severely diminished marginal utility. Two examples of gigantism in field artillery are the Big Bertha and the Paris Gun. Both were German weapons, but the French, Austrians and British also had super-heavy howitzers whose diameter exceeded 30 centimeters.[24] At the start of hostilities, the Germans possessed two of the L/12 42cm Type M-Great howitzer known as Big Bertha.[25] In total, ten of these howitzers were built.[26] Big Bertha could fire a round weighing 800kg over 12 kilometers. With delayed-point detonated fuses, it was effective at rapidly reducing fortified structures that were resistant to other forms of artillery. However, super-heavy artillery had a very limited amount of success. The slow rate of fire from these systems (about ten shots per hour for the Big Bertha) prevented them from effectively participating in preparatory fires. The super-heavy artillery forced planners to displace key targets beyond the range of these weapons.

Later in the war, both sides adopted tactics that favored a defense in depth. With defenders dispersed and mission-essential material moved to rear echelons, legitimate targets for super-heavy artillery became increasingly more difficult to find. Also, while the super-heavy artillery were more lethal, round for round, than heavy howitzers, they were not more survivable. Other disadvantages of these weapons included extensive site preparation and maintenance. This, combined with the slower rate of fire, meant that in the counter-artillery battle, the super-heavy artillery was at a disadvantage, gun for gun, compared with heavy artillery. Furthermore, the super-heavy artillery required considerably more resources to build and maintain. If the Big

Bertha represented the extreme in shell size, the Paris Gun represented the same for range; it could fire a 211mm round up to 130 kilometers.[27] The maximum rate of fire that could be achieved by this system was approximately 20 rounds per day.[28] The Paris Gun, named after its target, was used exclusively as a terror weapon and had no tactical effect other than as a target for the Allies to destroy, diverting resources away from the German lines for its defense.

At the conclusion of the war, the victorious Allies were generally satisfied with the existing tactics while the defeated Germans saw a need to reform. Both sides saw a shift toward the mean in artillery. There were fewer light field guns and fewer heavy artillery pieces greater than 200mm in caliber. Because of treaty restrictions, the German forces started World War II with less artillery than their doctrine required.[29] When they rapidly expanded their forces prior to and during the war, the number of divisions increased faster than artillery production could keep up. As a result, the Germans divisions were short on artillery during the entire conflict. The French influenced U.S. artillery development, because the American military was much smaller and more poorly equipped than that of its European counterparts during World War I. The light and medium calibers, 105mm and 155mm respectively, used by the French during World War I are the same as those used by American field artillery today.

The changes in artillery during World War II concentrated primarily on tactics. There were increased numbers of self-propelled artillery and artillery with armor, but the basic form and calibers had achieved maturity during the previous war. Casualties during the earlier phases of World War I were, in part, so catastrophic because the battle plans were treated as scripts. Artillery and infantry attacks were coordinated, but synchronization occurred through scheduling. Ground attacks would commence at a specific time regardless of the artillery's ability to reduce the objective. It was impossible for forward ground elements to request additional fires. Artillery and signal flares could be used to indicate changes in phases of the battle. Telephone communication existed between different headquarters, but it was unreliable. Runners were considered a reliable form of communication during combat. The first radiotelephones appeared at the end of World War I but did not become prolific until World War II.

Wireless communication dramatically altered the way in which artillery was utilized. Commanders and staff could monitor the battle as it progressed and allocate resources as needed. At the tactical level, forward observers attached to maneuver units could communicate directly with artillery units. Attacking forces could now request, spot and correct artillery, making indirect fires responsive and accurate to a degree that had not been seen since gun and infantry Soldiers stood shoulder to axle on the 19th century battlefield. Wireless communications allowed distributed firing positions to mass and allowed the shifting of fires on demand. The heavy siege weapons and massively grouped batteries in World War I were largely immobile. Because artillery with radios did not have to be collocated in order to fire together, artillery could be more mobile. Different units could move at different times and still fire together when they stopped. Mobility of artillery increased the difficulty of the counterbattery fires and the survivability of artillery units. Radio turned the battle plan from a rigid script that had to be followed regardless of the disastrous consequences into a guideline for that script.

Since World War II, there has been incremental progress in increasing range, but the limits of range effectiveness were seen with the Paris Gun during World War I. The trade space concerning barrel length, metal wear, weight and size that goes into determining the maximum weight of a howitzer has been well understood for almost a century. There is a decline in accuracy at the upper limits of range associated with the statistical variation of each round because of minute changes in the standardization of projectile and propellant manufacture, tube conditions and meteorological perturbations. Advanced modern artillery rounds that can track their own motions and modify their trajectories can overcome round-to-round variation.[30] Material advances resulted in minor improvements to the weight and the muzzle velocity of artillery tubes, but the major improvements in artillery have focused on speed and accuracy. The first electronic computer was designed to calculate ballistic solutions for artillery pieces.[31] Computations were recorded in tabular form and provided to artillery officers for use in the calculation of manual gunnery. The exponential growth in computational electronics has seen the computational gunnery migrate from the laboratory to the battery fire direction center (FDC) to computers located on each firing artillery piece. The automation of firing mechanics has proceeded at the same pace as gunnery automation.

Hydraulic systems that powered movement of the howitzer tube have evolved into a fully automated artillery system. The mobile field howitzer of the mechanized computational RMA has achieved its maturity in the form of Germany's *Panzerhaubitze* 2000 (*PzH*2000) and Sweden's Archer Artillery System. These weapons are fully automated 155mm howitzers that can receive a fire mission, load a round, orient the weapon and fire. The *PzH*2000 can fire up to ten rounds a minute.[32] This capability is a full order of magnitude increase in sustained rate of fire over contemporary howitzers. By adjusting tube elevation and propellant, the *PzH*2000 is capable of multiple rounds simultaneous impact (MRSI) fire missions.[33] A single piece of this type has the operational functionality of an entire battery. Future improvements in howitzer technology will be incremental increases in these designs. With regard to artillery, the next RMA will take the form of increasingly sophisticated projectiles.

In discussing the technological progress of field artillery, it is also valuable to examine the history of caliber and ammunition innovation. From the perspective of an artilleryman, combat can be simplified into the optimized, efficient transfer of destructive energy from one location to another while also preventing the adversary from accomplishing the same feat. The mechanism for transporting the energy is as varied as the ingenuity of the Soldier or the engineer. The suicide bomber personally carries the energy in the form of explosives to the target and then detonates the device. In the case of land mines and improvised explosive devices (IEDs), the energy is placed in a likely path of the target. The mine can be detonated either by its victim or by an operator. In kinetic energy weapons, the destructive energy is produced at the weapon, and the projectile carries the energy to the target in the form of mass and velocity. The KE projectile can be designed to penetrate the armor of the target, in effect transferring the energy to the interior of the target and not only to the surface. High-explosive rounds are transported to the target in a projectile similar to those of KE weapons, but the destructive energy of HE rounds is stored chemically in the explosive.

Simply transferring energy from one location to another is insufficient; enough energy must reach the target to achieve the desired effect. Often the desired effect is the destruction of the target, but a sufficient outcome can also be achieved at a much lower energy level. A wounded soldier and a killed soldier are both casualties. A tank can be rendered mission ineffective if it is destroyed. It is also mission ineffective if it cannot move or shoot, and its performance is greatly reduced if it cannot communicate. Much less energy is required to destroy the targeting optics on a tank, break the track or blow off the antenna than to penetrate the armor. "Minimum effective energy" is a concept defined as the lowest amount of destructive energy required to hit a target and achieve the minimum desired effect required to accomplish the mission. In the case of a radio frequency (RF) jamming system, the minimum effective energy might be microwatts of electromagnetic radiation provided for the duration of a broadcast. In the case of an antiaircraft system, several megajoules delivered by a high-velocity round may be required to achieve the desired effect. The caliber of a round is a linear dimension, but the designs of most high-explosive artillery rounds are scaled proportionally because of mechanical constraints produced by the cannon and atmosphere. With this design, a reasonable approximation expects the volume to scale as the cube of caliber. Explosives and chemical energy stored will scale with volume. The energy released in an explosion is spread out along a wave front. It is therefore safe to assume that the energy will, roughly speaking, decrease with the radius according to an inverse-square law relationship. The energy contained in the advancing shock wave will be dampened because some of the energy will be converted into heat. Based on these established relationships, doubling the caliber will increase the explosive in the device by a factor of eight. This doubling, however, will increase the radius required to achieve the same energy level as the smaller round by only about 2.8 times. The affected ground-surface area will be proportional to the energy of the explosives, but using the smaller round gives the artilleryman more control over the shape of the target area.

The relationship between the projectile size and the affected ground surface area can be demonstrated with weapons currently being used by the U.S. Army. The ratio between the 105mm HE round and the 155mm HE round is approximately 1:1.47. The cube of this is 3.17. The weight of the 105mm HE is 33 pounds.[34] The weight of the modern M795 155mm HE round is 103 pounds, excluding the fuse.[35] The ratio of about 3:1 for mass is valid. An effective radius is typically defined as the distance from the point where the round functions to the point at which it can achieve effects against dismounted troops standing in the open. Considerable resources and effort have been devoted to determining the effects of artillery and calculating the number of rounds required to destroy, neutralize or suppress a variety of military targets. When dealing with a single round, the rule of thumb for effective radius is 50 meters for a 155mm HE round and 35 meters for a 105mm HE round. These are round numbers, but the ratio is close to what would be predicted by comparing the weight of the projectiles. These rough calculations refer only to the energy of the shock wave and do not cover the velocity of metal fragments. The velocity of the fragments is governed by the more complex Gurney equations.[36] The distances described are those associated with soft targets such as personnel and light vehicles. Even a small amount of armor on a vehicle can greatly reduce the radius at which an artillery round can damage it.

There are fundamental limits in the amount of energy that can be stored chemically in the form of high explosives in a projectile. By increasing the projectile's complexity of design, the energy of a weapon of any caliber can be spread out at the target location. In theory, an optimally efficient distribution would be to deliver directly to the target the minimum energy necessary to destroy it. One method of delivering such energy is through fuel-air bombs, also called thermobaric weapons. These devices make use of atmospheric oxygen for combustion, while high explosives make use of a solid oxidizer. This design saves mass in the thermobaric device, which disperses to form a cloud; this cloud is subsequently ignited, generating a sustained shock wave.

Another technique that simultaneously disperses the payload of a projectile and concentrates the effects at the target is the use of submunitions. The 155mm dual-purpose improved conventional munitions (DPICM) round used by the U.S. Army contains 88 submunitions. The term "dual purpose" is a reference to the effectiveness of the weapon on both vehicles and dismounted infantry. The shape charge on the submunitions can penetrate up to 2.5 inches of rolled homogeneous steel armor, and the explosive fragments are effective against personnel.[37]

The submunitions are scattered from the base of the round above the target. Firing tables can be used to determine the number of rounds required to provide sufficient density of submunitions to make the impact of at least one against a vehicle a statistical certainty, though firing a sufficient number of rounds would leave many submunitions scattered. As previously mentioned, the most advanced rounds from the current RMA are capable of locating and engaging a target after the round functions. Its additional complexity reduces the overall explosive payload of the projectile but greatly increases the accuracy. There are drawbacks to distributed delivery systems—including the DPICM and smart weapons—that can find and attack vehicles on their own. The most obvious one is that the minimum safe distance for these weapons is much greater than for standard HE rounds. Earlier versions of DPICM had a significant number of submunitions that failed to function. Unexploded ordinance (UXO) constituted an unreliable low-density minefield, creating a problem for the belligerents on both sides. Therefore, UXO from early versions of submunitions—lacking the self-destructive mechanism that is present in modern models—continues to plague civilians in the vicinity of the affected area for years following the conflict.

The history of the evolution of battlefield fires will be discussed below to illustrate seven principles regarding the effects of the evolution of technology on development of weapons and the profession of arms.

Feedback. The first principle may be obvious, but it is worthwhile to state it explicitly: there is a feedback between weapons and tactics. As weapons are designed to meet the projected needs of soldiers, the tactics are modified to incorporate these new weapons. One possible outcome is a competitive development among all potential belligerents, which leads to varying degrees of parity. The other outcome is that one faction achieves dominance, and the other factions incorporate this asymmetry into their tactics and technology development. The mature embodiment of the technology is difficult to visualize during the early stages of development.

Materials. There are physical limits to the capabilities of weapon systems that are based on material properties. Without the development of new materials, performance improvements will be incremental and will usually come at the cost of another desirable characteristic. For example, a tradeoff exists between range and weight. For a projectile to travel further, the period of acceleration must be longer or it must be propelled by more energy. This desired travel requires either a longer barrel or a more robust chamber; either of these options requires more weight. The M777 towed howitzer weighs 40 percent less than the system it replaced—the M198—while it demonstrates comparable or slightly superior performance. This accomplishment was achieved by replacing steel with titanium. Similarly, there is a limit on energy that can be stored chemically in nitrogen-based high explosives or combustible hydrocarbons.

Complexity. Improved performance can be achieved through complexity. For example, DPICM simultaneously increased the effective area and concentrated the blast from the projectile. Complexity, however, is expensive. The price of complex systems will be substantially higher than that of simple systems. Additionally, complex systems are typically more maintenance-intensive and more prone to failure. There are also often unforeseen consequences that arise from complexity. In the case of DPICM, the dud rate led to risk for friendly and noncombatant vehicles moving through the target area. Additionally, the dud rate prompted political fallout as a result of civilian casualties from UXO. Problems such as these can be solved as they become apparent through additional complexity. This may or may not cause the cycle to repeat through a new set of second-order effects.

Optimization. Weapons will converge toward an optimal design over time. This convergence will result in the standardization of caliber among allies; more so, though, the physical properties of the weapons and the ballistics will optimize the designs. To destroy a specific type of target, a round must be of sufficient size. The drag on the round is a function of the shape and cross-sectional area. The momentum of the round is a product of the mass and the velocity. Add to these facts the necessity to mount the cannon on a mobile platform and to achieve a range of several dozen kilometers. Such a system is further constrained by the need for compatibility with existing transportation infrastructure. At this stage in the design process, the constraints on the system produce conformity in the main features of the weapons. The Russian military might prefer 152mm rounds for their 2S19, while the artillery of the Western Alliance uses 155mm; however, if one squints when looking at the gun or projectile, it is difficult to tell them apart.

Speed and Accuracy. The motto of America's Third Field Artillery Regiment is *celeritas et accuratio*. The motto's translation is "speed and accuracy." Through speed and accuracy, effective fires are delivered. This mantra is as true now as it was at the founding of the nation. Even before howitzers moved beyond the first terrain feature, the science of gunnery was devoted to ensuring accurate fires. Modern automated gunnery computation can calculate firing data that is accurate given the limits of statistical variation. The automation of gunnery followed by the automation of loading and positioning the howitzer have created a weapon system of unprecedented capability—the *PzH*2000. It is reasonable to anticipate that these capabilities will become expectations or necessities, thereby increasing the likelihood that they will eventually spread to other types of battlefield systems.

Price of Excess. If optimization represents a balance of desirable traits, extreme weapon systems sacrifice performance in most traits to achieve excellence in only one or two traits. The quintessential extreme weapon is the Paris Gun, which was, for all practical purposes, immobile. The rate of fire was measured in rounds per day while most artillery measures fire in rounds per minute. The Paris Gun consumed a large amount of resources, but it could launch an artillery round only as far as 130 kilometers. Furthermore, it contributed to the deaths of only 250 civilians;[38] even as a terror weapon, it was a failure. From a propaganda perspective, the murder of a few hundred civilians is not a catastrophe that would force a population to rise up and demand peace. Rather, it is seen as an atrocity that demands vengeance. The net effect of this program increased motivation and did not erode morale.

Commercial Technology. In the early half of the 20th century, the most advanced computer and communication technology was being developed and used by the military. Since the mid-1970s commercial research and commercially available technology have been competitive with military technology. The advances in computation that led to a computer mounted on every howitzer were developed by the civilian computer industry. A civilian with a smartphone has more reliable access to communications and better access to satellite imagery than an infantry rifleman using only his issued equipment. In the absence of a dedicated effort to correct this disparity, it is reasonable to assume that this trend will likely continue, and the gap in capabilities will continue to get wider.

The analysis of the development of field artillery was used to demonstrate the effect of technological development on warfare. Seven principles relating to the technological component of RMAs were identified. The next two case studies discuss four additional principles. The historical concept of combined-arms warfare will introduce the first two principles—lethality and information.

Case study 2: Maneuver

The engine of the tank is a weapon just as the main-gun.

Heinz Guderian[39]

The second historical topic to be considered is the concept of maneuver—which, as represented in its mature form as combined-arms warfare, is a system of systems. The technological embodiment of this concept in a single weapon system is the main battle tank—the fusion of armor, mobility and fire. The evolution of fires has been described in the previous section. Personal armor had been in decline since the emergence of the longbow and firearms. The effort required to carry the weight of metal armor was no longer justified by the amount of protection it provided. Metal armor strong enough to protect a person from high-velocity bullets was generally too heavy to transport more than a short distance. Although generals were unwilling to trade the cost of mobilizing foot soldiers for the marginal protection offered by armor, mounted soldiers continued to wear breast and back plates well into the 20th century. The gun shields added to field artillery pieces in World War I stopped the decline of armor. Prior to this shift, the increase in the lethality of weapons had convinced military planners that the effective means of protection was massive concrete and earthworks. The decreasing price of steel combined with field guns' proximity to the front convinced weapons designers to provide gun crews with at least a modicum of protection against small arms. Making this system mobile presented the next challenge.

One technical solution to the stalemate of World War I, as previously described, was the various permutations of howitzer artillery; another attempted solution was the tank. This weapon, first used by the British in 1916, proved effective despite trouble with terrain and frequent mechanical failure.[40] The technology was emulated by Britain's allies and adversaries. The French were much more enthusiastic about the technology, while the Germans built only a handful of tanks.[41] Near the end of the war, Allied doctrine incorporated the use of tanks to spearhead the breach of enemy lines. The infantry followed the tanks and exploited the breach. Essentially, this use of tanks is the same as the modern use of armor in a deliberate attack.

The Cambrian age of mobile warfare occurred during World War II. Armored and partially armored vehicles made appearances on the battlefield. Tanks with multiple turrets were used.[42] There were antipersonnel tanks armed with only heavy machine guns and mobile guns with armored sides and an open top.[43] Armored cars, infantry tanks, amphibious tanks and mounted guns were used to varying degrees.[44] The Germans had more than 20 different types of armored vehicles not including artillery and antiaircraft artillery.[45] The British and the Soviets each manufactured 15 armored vehicles, and the Americans manufactured 14.[46] These numbers count independent systems; they do not include variants on an individual design. The large number of systems is due in large part to the progress in technology. As soon as a tank went into production, the design for the next model began. But another reason for such variety is that tactics for fighting with these weapons were immature. The proper balance of armor, gun and engine had not been fully developed.

The first years of the Cold War made use of legacy tanks from World War II. The North Koreans fielded the Russian T-34, which was superior to the Americans' M24 Chaffee light tank.[47] The Americans seized the technological advantage in armored combat when they fielded the M46 Patton. The M24 weighed 20.2 tons, the T-34/85 weighed 35 tons and the M46 weighed 48 tons. At this point in the development of armored warfare, larger tanks had a competitive advantage; they could carry more gun, more armor and more power plant. This trend had a limit; at a certain point, size became a liability. The tanks in this war were certainly not the largest ever fielded. The Germans produced several tanks in excess of 70 tons during World War II. These heavy tanks were lethal to smaller tanks, but they were oversized for the technology at the time and suffered more casualties from mechanical failure than from enemy fire. The M41, a lighter, more mobile and more modern tank, was fielded during the Korean War; this tank, known by the end of the war as the Walker Bulldog, was used by some U.S. allies well into the 1980s.

During the Cold War there were two basic tank types—light and heavy. To make a tank lighter and more mobile, something has to be sacrificed; this sacrifice means a slower muzzle velocity or lighter armor. The M551 Sheridan was a light tank that compensated for the low muzzle velocity of its main gun by using a much larger caliber than is typically seen on a tank.[48] This 152mm HE shaped charge used the chemical energy in the projectile to destroy the target. The large size of the round also limited the rate of fire. The low muzzle velocity limited the effective range of the Sheridan and made it difficult to engage moving targets. During the Vietnam War, these tanks provided effective support to dismounted troops, but their light armor made them vulnerable to mines and rocket-propelled grenades (RPGs). By the 1990s the light tank had dropped out of the U.S. Army inventory.

A tank does not need to be fast *or* well-armed *or* well-armored; it needs to be all of these simultaneously. A new and powerful engine gave the M1 Abrams the ability to carry both gun and armor rapidly across the battlefield. Technology from the integrated-circuitry RMA provided controls for tube stabilization and targeting systems, resulting in a main battle tank that could accurately attack moving targets at the limit of its effective range. This tank was the heavyweight champion that was employed decisively against the Soviet tanks used by the Iraqis during the Gulf War in 1991 and again during the invasion of Iraq in 2003. The superiority of the Abrams is demonstrated by one report from the 24th Infantry Division (Mechanized) of having destroyed three T-72s while immobilized in the mud; it had received accurate fire from each of the T-72s.[49] The speed of a weapon system may be the constraint on mobility, but excessive logistical requirements can also be a constraint on a unit's movement. With the fuel consumption of the Abrams being measured in gallons per mile, a fleet of heavy expanded mobility tactical fuel trucks is required to keep the Abrams moving. In some instances during the 1991 Gulf War, units were unable to achieve their tactical objectives because of a lack of fuel.[50]

Deployability marked another strategic problem with the Abrams. Between the end of the Cold War and the late 1990s, the U.S. Army dramatically increased its peacetime operational tempo. As mission requirements for Soldiers increased, the difference between the amount of resources required to deploy Soldiers and the amount of resources required to deploy tanks became a concern to planners. Having the best main battle tank in the world was not such an asset if it was not possible to bring it on missions. America could deploy Soldiers in 48 hours, and the tanks would show up a month later, if at all. In 1999 General Eric K. Shinseki, then Chief of Staff of the Army, added the criterion of deployability to the existing requirements of an armored battlefield system.[51] This move eventually led the U.S. Army to adopt the Stryker as a combat vehicle.

The evolution of artillery is seen through an examination of shifts in optimization, material, complexity, excess and maneuver. The early extinction of tank variants that were not tactically effective illustrates optimization. After World War II, tanks had a basic form; designers and strategists tried a variety of combinations in the trade space regarding armor, firepower and mobility. As material quality and complexity improved, the quality of the tanks improved as well. The excess in size of the heavy German tanks allowed them to carry enough firepower and armor to be efficient tank hunters, but the size came at the price of reliability. A new principle learned from the evolution of tank warfare is the critical requirement for lethality in a weapon system.

Lethality. The most important characteristic of battlefield superiority in a weapon system is its ability to destroy competing systems. During the Yom Kippur War in 1973, the Israelis defended the Golan Heights with two brigades of armor and supporting artillery.[52] The Syrians attacked with five divisions. At the start of the battle, the Israelis had 180 tanks and the Syrians had 800. The Israelis inflicted tank casualties at a ratio of six to one. There is an art to war, and some of the losses can be attributed to superior training, but Israel's heavy British-made Centurion tanks were able to withstand the fire from the lighter Soviet-made T-55s and T-62s. This is not to say that the Centurions were invulnerable to their adversaries, but the Centurion tanks were better protected and more lethal than the T-55s and T-62s. The Centurion could engage another tank at a greater range, and a shot was almost invariably lethal. If a Centurion was hit, there was a good chance that it would remain functional and a better chance that it could be quickly repaired in the field. The insufficient lethality of the T-55s and the T-62s prevented them from inflicting a sufficient number of casualties to overwhelm the Israeli defenders. Lethality is the one aspect of the trade space that should never be neglected. Armor enhances survivability, but mobility also contributes to survivability. Camouflage and tactics improve survivability. Even lethality enhances survivability, but if a system lacks sufficient lethality, nothing can be done in the field to overcome this shortcoming.

The Battle of France, which took place in May 1940, further illustrates the importance of lethality in war, as well as highlighting the relationship between lethality and agility. After Germany and the Soviet Union invaded and subsequently partitioned Poland, the Germans transitioned the bulk of their air and ground forces from east to west. The consolidation and defense of the newly conquered territories in Eastern Europe was an economy-of-force mission. They had more than 3.3 million soldiers—approximately the same number as the Allies' combined forces. The Allies had 3,300 tanks to Germany's 2,400,[53] and they enjoyed an even more favorable advantage in artillery. As mentioned earlier, Germany never fully recovered from the artillery deficit resulting from the restrictions placed on it by the Treaty of Versailles. The Allies had an advantage of almost 2:1 (14,000 to the Germans' 7,400). Parity existed in the number of air-superiority fighters, though the German fighters were, in general, of superior quality compared to those of the Allied forces. The Germans' superior numbers in their ground attack aircraft greatly supported the ground forces and helped overcome the shortage of field artillery supporting the German forces. Close air support bombing proved particularly effective against Allied field artillery, which did not have antiaircraft artillery cover.

The Germans had trained according to a decentralized adaptive maneuver doctrine. The British and the French were using a more centralized organization that favored massing fires at key decisive points. As the aggressor, the Germans set the conditions of the battle. This circumstance forced the Allies to adapt to the German doctrine and allowed the Germans to seize and maintain the strategic initiative from the opening days of the war until the surrender of France. The Allied tanks were used for infantry support; therefore, although the Allies had more tanks, they did not mass tanks. Most French tanks were in tank battalions attached to an infantry division, where they could be spread among the subordinate units in the division.

The Battle of France involved millions of soldiers along a front that ran for hundreds of miles. The French focused on a defense in depth along the whole of the front. The Germans massed their forces and breached the Allied defenses in Belgium and Northern France. The early success of the Germans shocked the Allies and led the French to overestimate the strength of the Germans. The most obvious tactical advantage that allowed the Germans to overwhelm Allied defenses so quickly and soundly was their reliance on the internal combustion engine, which allowed for faster travel. There were times during the invasion when the mechanized forces of the Germans outpaced their far more numerous infantry; this occurred after the breach and during the exploitation. The gap between the strength of German armor and the strength of its infantry could have been exploited by the Allies if they had been more dynamic. Another German advantage was air supremacy, which they established by the fourth week of the invasion of France.

The Germans did not defeat the Allies in France through superior weapon technology. They did not have better tanks than the Allies. Rather, the Germans out-thought and out-fought the Allies. On the day the Allies surrendered, the French still had more and better tanks in the field than the Germans. The dynamic combined-arms maneuver doctrine gave the German commanders more agility than their adversaries. The Germans had a decisive technological advantage in communications. Almost every armored vehicle in the German army had a radio; thus, its commanders could more effectively control their forces and adapt to the changing battlefield conditions.[54] Possibly more important than letting the generals issue commands, radios allowed frontline soldiers to immediately inform the command and staff of the status, location and disposition of friendly forces and enemies engaged. Radio also gave ground commanders the capability to communicate directly with air support. Wireless communications allowed synchronization of all aspects of combined-arms warfare. The abundance of radios reduced the lag time between the intelligence collected by aircraft and the utilization of that intelligence in making battlefield decisions. With their superior communications, the Germans were able to operate within the Allies' decision cycle on the tactical level. This ability afforded the Germans the flexibility to adapt their battle plans to the tactical situation faster than their adversaries could adapt.

Information. The Battle of France is a historical example of how information dominance proved decisive. The strength of an army is its unity. In the absence of reliable communications, an army becomes a collection of individuals. Throughout the history of warfare, the operational tempo has only increased. A platoon or squad lacking reliable communication with its higher headquarters has only a battle plan and standing orders to synchronize its operations with the rest of the army. This issue is more problematic for automated systems. Remotely controlled systems cease to function in the absence of communication. Automated systems are limited by the sophistication of their software. Soldiers have been using kinetic energy weapons and chemical energetics as the primary means of dispatching their opponents for hundreds of years. The increased lethality of the modern infantry squad compared to its predecessors 50 years ago comes from improved situational awareness and the ability to bring timely and accurate external fires down on its opponents. On the future battlefield, the ability to communicate reliably while simultaneously preventing an adversary from doing the same will continue to prove decisive.

Case study 3: Weapons of Mass Destruction

> *Whether or not gas will be employed in future wars is a matter of conjecture, but the effect is so deadly to the unprepared that we can never afford to neglect the question.*
>
> John J. Pershing[55]

The final case study is, for the most part, an exception to the rules. It concerns weapons of mass destruction. The definition of WMDs has varied depending on the time, composition, method of utilization and audience. The military regards the standard definition of WMD as nuclear, biological or chemical weapons. This case study's analysis will focus exclusively on chemical weapons.

While chemical weapons were used before and after World War I, that conflict was the only occasion, so far, when these weapons were employed extensively by all belligerents. The first chemical weapons employed in World War I were irritants and largely ineffective.[56] The Germans were the first to use lethal toxic gas, even though it was prohibited by treaty at the time. Following the breach of the treaty, the Allies developed countermeasures and toxic gas of their own. During World War I, the chemical weapons used were blister agents and choking agents.[57] Initially, the defenses were toxin-specific. Therefore, as new poison gases were introduced, protective equipment had to be retroactively modified to defend against each new threat (i.e., poison). The defenses against the chemical weapons were effective if the soldiers were able to don them in time. In a war that saw more than 15 million military and civilian deaths, fewer than 100,000 were killed by poison gas.[58] Injuries from gas, however, reached more than one million.[59] This statistic indicates that the amount required to render a soldier incapable of performing his mission was much less than a lethal dose. In addition to the people injured or killed by gas, there were also psychological casualties. The trauma from being exposed to gas and seeing the effects of gas on fellow soldiers who did not put on their protective gear in time was at least as profound as the trauma from indirect fire.

Chemical weapons differ from kinetic energy weapons and explosives in the manner in which they cause destruction. One of the more lethal nerve agents is the chemical sarin, developed in the 1930s as a pesticide.[60] It was quickly recognized for its lethality to humans, and the research on it was transferred to martial applications. Though the Germans produced substantial quantities of sarin during World War II and both the Soviets and Americans stockpiled the toxin during the Cold War as their chemical weapon of choice, sarin was not used in battle until the Iran–Iraq War.

Sarin works by binding to the enzyme acetylcholinesterase. It is an irreversible inhibitor for this enzyme, which means that once the chemical bond is formed, that specific enzyme permanently ceases catalytic activity. Acetylcholinesterase breaks down the body's neurotransmitter acetylcholine following an action potential in a neuron. Thus, the neuron can return to a relaxed state and prepare for a subsequent action potential. In the absence of acetylcholine that would occur in the presence of sarin, the neuron remains in a constant state of stimulation. In sufficient quantities, sarin prevents respiration, leading to a coma and eventually death. Compared to the energy levels examined earlier in KE and HE weapons, the amount of energy required to kill a person chemically is trivial. Chemical weapons demonstrate the fragility of the human condition by penetrating a person's evolved defenses and attacking a single point of failure.

For the purposes of this paper, two guiding principles are associated with weapons of mass destruction:

- **Psychological impact.** The destruction of two cities through nuclear weapons prompted the Japanese to surrender. The shock value of the first release of chlorine by the Germans created an 8,000-yard gap in lines that were quickly becoming immobile.[61] The defenders fled before the cloud of noxious gas. The Germans missed an opportunity to exploit the breach because their commanders and soldiers were also wary of moving into an area that was recently occupied by poison gas. The fear of these technologies proved decisive during their initial application, and it was also sufficient to greatly restrict the subsequent use of them. Experiencing revolutionary technology can have a traumatic psychological effect on unprepared soldiers. This effect is often temporary, but dynamic commanders can exploit it. If automated systems ever largely or completely replace human warriors on the battlefield, adversaries lacking this technology will attempt to indiscriminately slaughter people with machines and advantageously erect political and legal obstacles. Engineers, planners and strategists need to factor nuclear technology's future into the design and operation of these systems.

- **Vulnerability.** The necessity to breathe serves as a conduit for the hostile delivery of toxins. Human beings are complex chemical factories, and the internal workings of people are subject to disruption by carefully selected chemicals. Analogies can be drawn between human vulnerability and that of automated systems. Automated systems are less vulnerable to chemical toxins, but they have their own vulnerabilities, such as the need to maintain almost constant communications, as previously discussed. The "mind" of a robot is a wholly created artifact and subject to corruption through malicious intent. Semiconductors are vulnerable to electromagnetic pulses and high-energy microwave radiation weapons. These issues are less problematic during asymmetric warfare, but in a conflict in which the adversary has the full resources of a nation state, any weakness that exists will be found and exploited.

Applying the principles previously described to the current RMA is not a trivial task. It is possible that with changes in the political–military landscape and advanced science, the lessons from history are false analogies. However, it seems likely that the next RMA will not be an incremental improvement but a revolutionary change. Current problems facing U.S. Soldiers can illuminate the first stage of this RMA. In the October 2010 article "Small Unit Dominance," retired Major General Robert Scales examines the technological progress—or lack thereof—of infantry combat.[62] He issues a call to action for more capital investment in doctrine, training and support, as well as in arms and equipment available to ground Soldiers. Scales examines the age of some of the weapons, including personal firearms used by the Soldiers. The extended service of the M2 .50-caliber machine gun is a testament to the maturity of firearms. There have been refinements to this gun over the past century; regarding the use of chemical energy to accelerate projectiles, however, there is not much room for improvement. Many advances in infantry weapon effectiveness have been in the form of improved targeting optics, such as night-vision devices, telescopic sights and laser targeting. Only very recently has the integrated-circuit RMA begun to reach down to man-portable small-caliber weapon systems.

Breakthroughs such as the XM25 Individual Airburst Weapon System (IAWS) have proven effective and have increased the lethality and accuracy per shot. This weapon is an improvement over existing grenade launchers and is a first step to integrating information technology into personal weapons. However, this technological progress results in increased weight of the weapons and a smaller-caliber projectile, and the tradeoff is not worthwhile. The previous version of the personal grenade launcher is the 40mm M203. The M203 has a muzzle velocity of 76 meters/second (m/s)[63] while the XM25 has a muzzle velocity of 210 m/s.[64] This increased velocity results in a flatter trajectory, better accuracy and less round-to-round variation. In addition, the XM25 is semiautomatic, which produces a higher rate of fire. The operator uses the weapon to program the round that functions at a range resulting in an airburst over the target. The range to the target is determined by a laser range finder and automatically programmed onto the projectile. Reports from the field indicate that Soldiers are greatly satisfied with the results of this weapon.[65]

The XM25 demonstrates the potential of integrating information technology, but better personal weapons are not the path to an RMA in small-unit tactics. This new weapon will give an advantage to Soldiers but not a decisive one. The range of the XM25 is 700 meters for area targets. The range of the Browning M2 machine gun is 2,000 meters. That the M2 preceded that XM25 by 90 years gives further perspective on the maturity of personal weapons: weapons with greater accuracy, greater range and greater lethality are needed to provide battlefield dominance to the small unit. Unfortunately, there is a limit to the amount of weight a Soldier can carry and the amount of recoil he can absorb. As mentioned earlier, the increased lethality of modern Soldiers has come from improved training and the ability to bring external fires onto the battlefield, whether in the form of artillery, mortar or air support. These conditions will also be present in the next RMA.

Remotely controlled robots first appeared in combat when they were used to deliver demolitions and as a kind of ground-based torpedo by Germany in World War II.[66] The remotely controlled vehicles were too sluggish and too vulnerable to human response. The agility of a soldier on the ground or operating an armored vehicle provided a competitive advantage over remotely controlled systems in combat during that war. Currently a number of remotely controlled UGS are used by the U.S. Army for various dangerous tasks. As the technology improves, remotely controlled robots will become more prolific. The interface between the robot and the human is still in its first generation. Soldiers who are actually on the battlefield enjoy a situational awareness advantage over remote operators. Of course, the remote operators enjoy the advantage of being removed from danger. As the technology improves, data from a greater number of increasingly different types of sensors will be integrated into the remote interface. This technology will include not only data from sensors mounted on the robot but also data from other automated systems scattered across the battlefield. At some point, a threshold will be reached and that situational awareness advantage will pass to the remote user. It will be some time before such vehicles are fully automated.

The problem of maneuver is separate from the problem of situational awareness. When the problem of maneuvering a remote vehicle long distances, away from improved surfaces, in forests and over mountains is considered, the challenges facing automated UGS become daunting. With human drivers, tracked and wheeled vehicles get stuck in the mud; immobilized robots would compound this problem. Furthermore, these systems are intended to be used against an intelligent adversary capable of analyzing weaknesses. The task of developing intelligent automated UGS capable of independent off-road navigation appears monumental in light of remotely controlled capabilities.

Fully automated UGS are so far away from being mobilized that, from the perspective of Soldiers currently in the Army, they might as well not look forward to such a time. A private or a lieutenant in the Army today might serve long enough to see a fully automated UGS on the battlefield that is capable of independent maneuver, target identification and engagement, but it seems unlikely. Battlefield decisions are critically important and incredibly complex life-or-death calls. Regardless of the sophistication of the software, it will be a long time before generals and captains are willing to delegate such judgment to a machine.

Early successes in automated ground systems are essential to begin the feedback process. This concept is known as Evolutionary Acquisition, which, according to the Defense Acquisition University, "builds and fields core portions of a system, selectively evolving it through phased upgrades based on user feedback."[67] Because of the previously described difficulties associated with maneuver, the next phase of the RMA should be fire support. This is analogous to the rapid development of field artillery preceding the mechanization of warfare. Autonomous off-road travel may be difficult, but traveling on improved surfaces and following soldiers are much more manageable tasks for UGS. An automated gun system providing accurate fire support of a smaller caliber and at a higher rate of fire than modern artillery could lead to battlefield dominance as enjoyed in the air and at sea.

The weapon system of the current RMA would provide supremacy to the infantry squad and platoon—and would supply an automated automatic grenade launcher. This weapon system would be capable of non-line-of-sight (NLOS) target engagement. While not an actual extant weapon system, it can be referred to as an Automated Automatic NLOS Grenade Launcher (AANGL). This weapon could be mounted on a self-propelled UGS platform such as the Army's Modular Universal Laser Equipment (MULE)[68] or on an existing military vehicle such as a High-Mobility Multipurpose Wheeled Vehicle (HMMWV). It could also be dismounted as a stationary weapon. Currently, weapons mounted on UGS and remotely operated weapons, such as the Common Remotely Operated Weapon Station (CROWS), are optically targeted. The NLOS version of CROWS would rely on mechanical proprioception-based targeting. Proprioception is a biological term that refers to an animal's perception of the status, position and orientation of the animal's own body. Roboticists reference the term when discussing data collected by sensors on a robot that provides information on its position, status and orientation. This type of targeting that relies on knowledge of the target's location and the weapon system's location and disposition is essentially how modern artillery is used. An automated NLOS fire-support system would also require accurate predicted fire for artillery gunnery. A forward observer reports the location of the target; a fire-direction center or automated-computerized artillery system computes the proper azimuth, elevation and propellant charge to be used on the gun to bring the round on target. The system proposed would be a small-caliber version of the Krauss–Maffei Wegmann Artillery Gun Module (AGM),[69] which is a fully automated version of the gun on the *PzH*2000. Divorcing sensor and shooter led to the dominance of howitzers over field guns in the late 19th and early 20th centuries. Generally speaking, sensors can be made much more cheaply and are more disposable and much easier to conceal than weapon systems. If one has information dominance or even just reliable communications, there is no tactical reason why sensor and shooter need to be collocated. It is worth repeating that the NLOS systems can support a much larger area of the battlefield than an optically targeted system.

There is a need for smaller-caliber and more responsive fire support at the small-unit level. The time between requests for fire from artillery and mortars and the time that rounds impact on the target is usually measured in minutes. For artillery near the maximum limits of their range, the time of flight of the projectiles can take minutes, not including processing time. The use of fire support by ground forces has been constrained at various times during recent conflicts based on political considerations and the rules of engagement.[70] In addition, artillery and close air support are scarce resources shared by a number of supported ground units. Even mortars, which are organic to the infantry, may be tasked to provide priority support to a different unit or may be out of range of the unit that needs them. An organic asset at the platoon or squad level would ensure that the ground Soldiers are never left without support. To improve responsiveness, a streamlined targeting interface would be needed to greatly reduce mission processing time by the observer.

A small-caliber NLOS weapon system could be useful in the full spectrum of military conflict. On the lower end of the spectrum—in operations other than war (OOTW)—are operations such as peacekeeping, humanitarian assistance and noncombatant evacuation. During these operations, the AANGL could make use of nonlethal or less-than-lethal ammunition such as smoke grenades or riot control agents (e.g., tear gas). This capability would provide ground forces with a responsive mechanism for fire support without escalating the level of violence. Officers planning the defense of key sites could make use of rolling barrages of tear gas with a predetermined, calculated gas density. This defensive plan would allow planners to determine the desired concentration and gradient in gas required to displace a crowd while minimizing risk of injury to civilian and military personnel. At the high end of OOTW and during limited conflicts, the proposed system could be used as it was conceptually intended: to provide fire support to light ground forces. The fact that the caliber is smaller than that of mortars and artillery is an asset because it reduces the amount of collateral damage and therefore increases the range of situations for which this weapon could be an appropriate response.

This weapon could be used during limited and general war on large-scale battlefields with heavy mechanized forces. It could continue to be used in support of dismounted forces. While the weapon's range limits its effectiveness, the caliber is sufficiently large that it is capable of achieving decisive effects against virtually all battlefield targets with the possible exception of heavy main battle tanks. The projectile may not be able to penetrate the armor of a modern main battle tank, but it could be more than capable of destroying the communication system, damaging the targeting optics, breaking the track or rendering the main gun inoperable. The DPICM used against the Iraqi army during the Gulf War was referred to as "steel rain" by the Iraqis, and it was devastating. The DPICM is a shell for transporting and scattering 40mm shaped-charge submunitions. The AANGL would not scatter its rounds across a target relying on probability for an impact; to achieve the desired effect, the rounds would be deliberately aimed to hit a specific target in sufficient numbers. The analogy would not be rain falling on a target—it would be a garden hose pouring water. While a hose is less poetic than rain, it will get you much wetter.

The implications of the AANGL will be considered on each of the following systems that comprise the Battlefield Operating Systems (BOS).

- **Maneuver.** The proposed weapon system is a fire-support system; however, its small size would allow it to be mounted on a mobile platform such as a HMMWV or UGS. Its shorter range limits its requirements for more accurate survey. Because of these factors, the weapon could maneuver with Soldiers and fire either on the move or on the halt. Its high rate of fire would make it ideal for suppressive fire.
- **Fire Support.** The AANGL would provide fire support to ground forces. If the system's targeting were to be integrated with counterfire radar, this weapon would prove particularly effective against mortars. The smaller caliber would minimize collateral damage when responding to fire from urban areas. The problem with operating the system in this capacity is its limited range; all modern mortars have a maximum range that exceeds that of the system described.
- **Air Defense.** The automated firing system could be used to engage small aircraft. The characteristics of this system would be particularly well adapted to engage small, slow-flying UAS. There are no weapons in the current U.S. arsenal designed to engage the smaller UAS. To attack aircraft, the system would have to be modified. The required changes would include alterations to allow the use of high-velocity projectiles and specially designed rounds with proximity fuses. The real difficulty would be the design and manufacture of a system capable of tracking and computing the intercepts of UAVs.

- **Command and Control.** Automated systems are poor decisionmakers; they lack the initiative, intuition, creativity and versatility that is characteristic of the American Soldier. Their use will increase the requirements for command and control at the squad, platoon and company levels. As evident from increasing requirements for information processing at the small-unit level, intelligence personnel have been attached to some maneuver companies as company intelligence support teams. This trend will continue as dismounted warfare becomes increasingly capital-intensive. A company or platoon operations center that is physically removed from the fighting would be an ideal place for processing sensor data and prioritizing automated system fires. Fire-support Soldiers in an operating center could communicate with their supported Soldiers and command automated systems to support the infantryman, while intelligence analysts could process sensor data into a comprehensive picture of the battlefield.
- **Intelligence.** Automated systems are both producers and consumers of intelligence. The AANGL would be a consumer. The system realizes its full potential when remote-sensor data integrates into the targeting process. When the system is operated in this manner, the enemy is engaged from a concealed position at the extreme range of the weapon system. A number of systems that are in production (or soon will be) would be ideal for nominating targets. The Base Expeditionary Targeting and Surveillance Sensors–Combined is currently being fielded in Afghanistan. The Army Research Laboratory has developed the Compact Radar, a ground-based, man-portable moving-target indicator radar. Data from acoustic sensors, such as the Unattended Transient Acoustic Measurement and Signature Intelligence Sensor, could be another source for targeting data. Integration of sensor and shooter could be fully automated in a permissive environment, or a fire-support expert could be included in the process to provide additional judgment.
- **Mobility and Survivability.** The weapon system described could facilitate survivability by creating and sustaining a smoke screen. More sophisticated smoke rounds might allow the operator to initiate and terminate the release of smoke. The AANGL could help in countermobility by operating as an area-effect minefield. It could be placed in defilade on the battlefield with passive defenses around its firing position. As the enemy moved into the engagement area, the system could fire continuously at targets provided to it from remote sensors. The fire could continue until ammunition stores were exhausted, at which point a mobile system could self-extract or an immobile system could self-destruct.
- **Combat Service Support.** An automated system would have a smaller logistics footprint at the operational level than that of the number of combat Soldiers required to deliver a similar amount of firepower. The ability to dispense the required amount of firepower directly onto the target may reduce the logistics footprint compared to the artillery's ability. The cost per round and cost as a function of effects would compare favorably regarding missile technologies. If Soldiers begin to rely heavily upon this system, ammunition consumption at the small-unit level may increase.

Conclusion

While this proposal is a product of the analysis of modern requirements of the ground Soldier and historical analysis, it is *just* an idea. A more scientific approach to equipping light ground forces involves the evaluation of potential new inventions in computer simulations. The combat effectiveness of revolutionary technologies could be compared to the marginal increases in range or accuracy of improved small arms. This comparison may provide a scientific approach to optimizing force structure and equipment combinations for small units. In 2004 the U.S. Marine Corps developed a modified version of the computer game "Close Combat."[71] The new version—named "Close Combat Marines"—is used at the Marine Corps' Infantry Cognitive Skills Lab. The Commandant of the Marine Corps references such simulation as a possible resource for training. One of dozens of computer simulations used to train U.S. ground Soldiers, this game may or may not be sufficiently realistic to provide actionable data in simulations designed to determine the effectiveness of technology. Nonetheless, this simulation or a more accurate one would certainly do a better job than the absence of any simulation of quantifying the utility of new technologies. Use of simulation of small-unit combat operations to improve small-unit leadership was another point addressed by General Scales.[72] As technology improves and engineers are provided with greater degrees of freedom in developing automated weapon systems, the ability to evaluate technologies before developing them will become critical.

The AANGL weapon system would require an engineering effort to integrate the system components, but additional research in developing new technologies would not be required. A first-generation version that could fire a single type of projectile at a single muzzle velocity would have a developmental time measured in months, not years. All components of the system are available as commercial-off-the-shelf (COTS) technology or government-off-the-shelf (GOTS) technology. Kongsberg Defense, developer of the CROWS, has a version that can mount an MK-19 40mm grenade launcher. Automated gunnery for determining ballistic solutions goes back to the beginning of computing. The components are extant now and could simply be integrated into a firing system that can communicate with an easier user interface. The maximum effective range of the MK-19 is over 1,500 meters. More than 90 percent of American casualties in Afghanistan have occurred within 400 meters of a road.[73] A CROWS with an MK-19 using modified gunnery software mounted on a HMMWV or MULE platform could have provided crucial fire support to those Soldiers. A functional prototype could be assembled by any major university's robotics department; the development of this kind of weapon system is well within the capability of most nation states. When considering how achievable and decisive such a weapon would be, it is also worthwhile to remember that the advantages of an RMA accrue almost entirely to the early adopters.

The next RMA is approaching. There is a finite amount of fire power using chemically stored energy that is transportable on a Soldier. A way to overcome this limit is to increase the ease and responsiveness with which Soldiers can bring remote fires down upon an adversary. The automated automatic grenade launcher bridges the gap between man-portable weapons and overpowering NLOS systems such as artillery, mortars and rockets. The critical enabling technology required to bring automated weapons technology to the ground Soldier is proprioception-based targeting. Weapons based on this targeting process would provide faster, more responsive fires and be less destructive. Such targeting continues the trend that was started by precision-guided munitions, which reduced the destructive energy to the most effective minimum.

To ensure that each defense research dollar is used efficiently, decisionmakers must successfully integrate input from experts on both the profession of arms and engineering. The history of weapon development can provide a foundation of knowledge in illustrating the aspects of battlefield technology that is crucial. Simulation of technology during the development stage is a crucial part of the process. The technology described could be a productive next step in the process of bringing the decisive capital-intensive technologies that have led to supremacy in the air and on the sea to support the person who is suffering the most and doing the heavy lifting in our modern conflicts—the infantry Soldier.

Endnotes

1 Sandra I. Erwin, "U.S. Military Reigns Supreme in the Sea and Air: But Why Not on the Ground?" *National Defense*, 27 September 2010, http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?ID=208.

2 Department of the Army, Field Manual 3-24, *Counterinsurgency*, December 2006, http://www.fas.org/irp/doddir/army/fm3-24.pdf; and David Kilcullen, "Twenty-Eight Articles: Fundamentals of Company-level Counterinsurgency," *Military Review*, vol. 86, no. 3, May/June 2006, pp. 103–108.

3 James Dunnigan, "Afghans Rediscover the Lee-Enfield," *Strategy Page*, 22 January 2009, http://www.strategypage.com/dls/articles/Afghans-Rediscover-The-Lee-Enfield-1-22-2009.asp.

4 Williamson Murray and MacGregor Knox, "Thinking about revolutions in military affairs," *The Dynamics of Military Revolution, 1300–2050* (New York: Cambridge University Press, 2001), pp. 1–14.

5 *Ibid.*

6 Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA[ALT]), "Excalibur (XM982)," *Weapon Systems 2011: America's Army, The Strength of the Nation* (Washington, DC: Department of the Army, 2011), p. 94.

7 Picatinny Arsenal, "Smart Munitions," http://www.pica.army.mil/picatinnypublic/products_services/products01.asp, accessed 8 March 2011.

8 "Man Transportable Robotic System," *FY2009–2034 Unmanned Systems Integrated Roadmap* (Washington, DC: Department of Defense, 2010), p. 94, http://www.acq.osd.mil/psa/docs/UMSIntegratedRoadmap2009.pdf.

9 QinetiQ North America, "MAARS Robot," http://www.qinetiq-na.com/products/unmanned-systems/maars, accessed 25 January 2012.

10 Alexander Ludeke, *Weapons of World War II* (Cambridge, UK: Parragon, 2007), pp. 182–183.

11 *Ibid.*, pp. 180–181.

12 Janice E. McKenney, *The Organizational History of the Field Artillery 1775–2003* (Washington, DC: Army Center of Military History, 2007), pp. 35–46.

13 *Ibid.*, pp. 47–49.

14 W. S. Curtis, "Long Range Shooting: An Historical Perspective," *Long Range Rifle Fire*, 2001, http://www.researchpress.co.uk/longrange/lrhistory.htm, accessed 9 March 2011.

15 McKenney, *The Organizational History of the Field Artillery 1775–2003*, pp. 47–73.

16 Bruce I. Gudmundsson, *On Artillery* (Westport, CT: Praeger, 1993), pp. 1–16.

[17] *Ibid.*

[18] *Ibid.*, pp. 17–28.

[19] Jonathan Irving and Cynthia J. Lunine, *Earth: Evolution of a Habitable World* (Cambridge, UK: Cambridge University Press), p. 224.

[20] *Ibid.*, p. 230.

[21] Gudmundsson, *On Artillery*, pp. 29–41.

[22] *Ibid.*

[23] *Ibid.*

[24] Ian V. Hogg and L. F. Thurston, *British Artillery Weapons and Ammunition 1914–1918* (London: Littlehampton Book Services, 1972), p. 180; and Archer Jones. *The Art of War in the Western World* (Champaign, IL: University of Illinois Press, 2000), pp. 449–451.

[25] Herbert Jäger, *German Artillery of World War One* (Marlborough, UK: Crowood, 2001).

[26] *Ibid.*

[27] Henry W. Miller, *Paris Gun* (Uckfield, UK: Naval and Military Press, 1930).

[28] *Ibid.*

[29] Gudmundsson, *On Artillery*, pp. 107–123.

[30] ASA(ALT), "Excalibur (XM982)," p. 94.

[31] Martin H. Weik, "The ENIAC Story," Ordnance Ballistic Research Laboratories, 1961, http://ftp.arl.mil/~mike/comphist/eniac-story.html, accessed 9 March 2011.

[32] "*PzH* 2000," Army-Technology.com, http://www.army-technology.com/search/?q%5B%5D=+PzH+2000, accessed 9 March 2011.

[33] *Ibid.*

[34] "105 mm HE M1 Ammunition," Thales Group, http://www.thalesgroup.com/Workarea/DownloadAsset.aspx?id=8377&LangType=2057, accessed 9 March 2011.

[35] "M795 Projectile 155mm High Explosive HE," GlobalSecurity.org, http://www.globalsecurity.org/military/systems/munitions/m795.htm, accessed 9 March 2011.

[36] R. W. Gurney, *The Initial Velocities of Fragments from Bombs, Shells, and Grenades*, BRL-405 (Aberdeen, MD: Ballistic Research Laboratory, 1943).

[37] "Dual-Purpose Improved Conventional Munitions," GlobalSecurity.org, http://www.globalsecurity.org/military/systems/munitions/m795.htm, accessed 9 March 2011.

[38] Henry W. Miller, *Railway Artillery* (Washington, DC: Government Printing Office, 1921), p. 731.

[39] Oskar Munzel, *Die Deutschen gepanzerten Truppen bis 1945* (Munich, Germany: Maximilian–Verl, 1965), p. 159.

[40] Geoffrey Parker, *The Cambridge Illustrated History of Warfare* (Cambridge, UK: Cambridge University Press, 1995), p. 379.

[41] Michael Duffy, "Weapons of War—Tanks," First World War.com, 2009, http://www.firstworldwar.com/weaponry/tanks.htm, accessed 16 March 2011.

[42] Ludeke, *Weapons of World War II*, p. 116.

[43] *Ibid.*, pp. 62–139.

[44] *Ibid.*

[45] *Ibid.*, pp. 62–87.

[46] *Ibid.*, pp. 99–139.

[47] George F. Hofmann, "Tanks and the Korean War: A case study of unpreparedness," *Armor*, September/October 2000, http://www.korean-war.com/Archives/2002/04/msg00044.html, accessed 16 March 2011.

[48] Bruce I. Gudmundsson, *On Armor* (Westport, CT: Praeger, 2004), pp. 169–170.

[49] *Ibid.*, p. 174.

[50] *Ibid.*

[51] General Eric K. Shinseki, "The Army Vision: Soldiers on Point for the Nation . . . Persuasive in Peace, Invincible in War," speech at the Annual Meeting of the Association of the United States Army, Washington, DC, 12 October 1999, http://dacp16.apgea.army.mil/omstragplan.html, accessed 14 March 2011.

[52] Gudmundsson, *On Armor*, p. 167.

[53] Klaus Maier and P. S. Falla, *Germany and the Second World War, Volume 2: Germany's Initial Conquests in Europe* (Oxford, UK: Oxford University Press, 1991).

[54] Mark Healy, *Panzerwaffe, Volume 2: The Campaigns in the West 1940* (London., UK: Ian Allan Publishing, 2008), p. 23.

[55] Charles E. Heller, *Chemical Warfare in World War I: The American Experience, 1917–1918* (Fort Leavenworth, KS.: U.S. Army Command and General Staff College, 1984), p. 1.

[56] *Ibid.*, p. 7.

[57] *Ibid.*

[58] Michael Duffy, "Weapons of War–Poison Gas," First World War.com, 2009, http://www.firstworldwar.com/weaponry/gas.htm, accessed 16 March 2011.

[59] *Ibid.*

[60] "A Short History of the Development of Nerve Gases," Noblis, 2009, http://noblis.com/MissionAreas/nsi/BackgroundonChemicalWarfare/HistoryofChemicalWarfare/Pages/HistoryNerveGas.aspxwar.com/Archives/2002/04/msg00044.html, accessed 16 March 2011.

[61] Heller, *Chemical Warfare in World War I*, p. 9.

[62] Major General Robert H. Scales, USA Ret., "Small unit dominance: The strategic importance of tactical reform," *Armed Forces Journal*, October 2010, http://www.armedforcesjournal.com/2010/10/4757970, accessed 16 March 2011.

[63] Art Pizza and Melissa Wanner, "Product Improvement 40mm Ammunition NDIA," 19 May 2005, Defense Technical Information Center, http://www.dtic.mil/ndia/2005smallarms/thursday/pizza.pdf, accessed 16 March 2011.

[64] "XM25 Counter Defilade Target Engagement System," PEO Soldier/ATK, 2009, http://www.atk.com/capabilities_space/documents/sw_iw_xm25.pdf, accessed 25 January 2012.

[65] Lance M. Bacon, "'Punisher' gets its first battlefield tests," *Army Times*, 14 February 2011, http://www.armytimes.com/news/2011/02/army-xm25-punisher-battlefield-test-021411w, accessed 16 March 2011.

66 Ludeke, *Weapons of World War II*, p. 178.

67 "Systems Engineering Intermediate SPRDE, Part 1," Defense Acquisition University, https://learn.dau.mil/CourseWare/800840_4/media/sys202_print_tf.pdf, accessed 16 March 2011.

68 "Multifunction Utility/Logistics Equipment Vehicle (MULE)," *FY2009–2034 Unmanned Systems Integrated Roadmap* (Washington, DC: Department of Defense, 2010), p. 127.

69 "Artillery Gun Module (AGM)," Krauss–Maffei Wegmann, http://www.kmweg.de/10843-JTBEJTBBPSZkb209ZG9tMSZsPWVu--~PRODUKTE~artillerie~agm~agm.html, accessed 16 March 2011.

70 Yochi J. Dreazen, "U.S. Revisits Afghan Battle Rules," *Wall Street Journal*, 24 June 2009, http://online.wsj.com/article/SB124571281804038963.html, accessed 16 March 2011; and Dan Lamothe, "Congress briefed on rules of engagement," *Marine Corps Times*, 15 October 2010, http://www.marinecorpstimes.com/news/2010/10/military-roe-afghanistan-walter-jones-david-petraeus-101510, accessed 16 March 2011.

71 Sandra I. Erwin, "Games Are Gaining Ground, But How Far Can They Go?" *National Defense*, December 2005, http://www.nationaldefensemagazine.org/archive/2005/December/Pages/Games_Are5484.aspx, accessed 16 March 2011.

72 Scales, "Small unit dominance."

73 *Ibid.*