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FUTURE WAR PAPER

PRECISION ARTILLERY FIRES: LEVERAGING ADVANCES IN FIELD ARTILLERY MUNITIONS TO IMPROVE FUTURE BREAKTHROUGH AND EXPLOITATION OPERATIONS

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTERS OF OPERATIONAL STUDIES

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“If there is one clear lesson from the Gulf War, it is don’t ever fight the United States on its own terms.”

British Colonel J.B.A. Bailey

Introduction

Future enemies of the United States have learned valuable lessons from the swift defeat of Iraqi forces during both the Gulf War and 2003 invasion of Iraq. As such, America’s future enemies can be expected to employ a combination of technology and innovative tactics to overcome U.S. tactical advantages with their goal being to prevent U.S. ground forces from penetrating their defensive system in a fashion similar to that which occurred against Iraqi. To ensure the U.S. military maintains the capability to rapidly breakthrough and exploit a defense in depth against the most modern opponents, the U.S. Army and Marine Corps must explore ways of using emerging technologies to advance current breakthrough and exploitation techniques. One emerging technology which looks to improve upon historical methods is the development of low cost precision-guided artillery munitions which have the potential to bring about the next evolution in breakthrough and exploitation techniques by changing the way artillery supports maneuver forces and by increasing the lethality of artillery against modern targets. Similarly, precision-guided artillery munitions provide potential solutions to some of the issues faced by maneuver commanders during historical breakthrough and exploitation operations as well as emerging concerns as it relates to future operations. In short, precision-guided artillery munitions will allow a breakthrough force to achieve faster and more predictable effects, reduce the logistical burden on artillery forces, and allow artillery forces to task organize into smaller elements that provide greater flexibility and mobility for the supported commander.

Most research to date regarding precision-guided artillery munitions has looked at its potential to limit collateral damage when attacking targets in populated areas. The goal of this

paper is to look beyond the narrower issue of collateral damage and explore the broader impact of precision-guided artillery munitions on future offensive operations. More specifically, this paper will explore how precision-guided artillery rounds might enhance or change the way artillery is employed in support of a breakthrough attack and what effect that change will have on friendly tactics. As history has shown, a new weapon with a high probability of killing can change the character of war.¹

Besides the operational significance of maintaining the ability to penetrate and exploit an opponent's defensive system, there are three historical or emerging concerns that make this subject worth studying. First, towed artillery, which makes up the preponderance of U.S. artillery assets, is rapidly losing the ability to keep pace with U.S. ground forces that are increasingly motorized or mechanized. This presents a tactical dilemma for the ground commander who must choose between speed, thus placing greater reliance on direct fire assets or support from non-organic assets, or slowing his movement to a rate that ensures organic artillery coverage is maintained. Slowing down the attacker's momentum reduces the likelihood of a successful breakthrough.² Secondly, the capability and survivability of enemy forces continues to increase. Potential adversaries are becoming increasingly mobile with vehicles having heavier armor making them harder to suppress or neutralize.³ Enemy forces are also dispersing in order to take advantage of increased weapons ranges as well as to mitigate the effect of modern U.S. weapons against area targets. Finally, enemy forces can be expected to have a greater number of artillery tubes and rocket launchers than U.S. forces as well as significant munition stockpiles.⁴ With these greater numbers they can effectively neutralize an attacking force as well as make massing of friendly forces dangerous.⁵ The final reasons this subject is worth studying is that it must be assumed that future adversaries will have the capability to contest air superiority thus

reducing the number of aircraft available to provide close air support during breakthrough and exploitation operations. U.S. forces must ensure they have the capability to penetrate an enemy defense in depth without significant close air support. This will require ground forces to rely more heavily on organic assets during an attack. In summary, future breakthrough operations will likely place a greater requirement on artillery while its effectiveness against enemy forces will likely be reduced, without a change to current artillery capabilities and employment techniques. Precision-guided artillery munitions provide a potential cost-effective solution to these problems.

The Future of Precision-Guided Artillery Munitions

The continued development and fielding of precision-guided artillery munitions will change the way artillery supports maneuver forces, giving U.S. forces an advantage during breakthrough operations.⁶ Until the invention of guidance, all artillery rounds were affected by the fundamentals of ballistics, which meant that once a round left the tube its flight path could not be corrected.⁷ The first precision-guided artillery rounds entered service in the 1980s. The Sense and Destroy Armor (SADARM) round and the laser guided Copperhead round were developed to kill Russian armor attacking into Europe.⁸ These weapons were expensive but proved highly capable of destroying point targets. In 2006 the next generation of precision-guided artillery munitions, the M982 Excalibur round, entered service. The Excalibur round is a cannon fired Global Positioning System (GPS) guided munition with a high explosive warhead that has a Circular Error Probable (CEP) of less than 10 meters at ranges up to 40 kilometers.⁹ Future versions of the Excalibur round currently in testing have achieved an accuracy threshold of 5 meters CEP.¹⁰ Compare this to a conventional artillery round that has a CEP of almost 267 meters at 30 kilometers of range and one sees that one or two rounds of precision-guided

munitions will achieve the same effect that would require hundreds of conventional rounds to achieve. At a cost of approximately \$70,000 per round, the Excalibur round is not cost effective for use on a tactically significant scale. Excalibur was designed to attack High Payoff Targets using precision to achieve the desired effect rapidly along with targets that pose a high collateral damage concern.

The next generation precision-guided artillery round is the M1156 Precision Guidance Kit (PGK) which is a GPS guided fuze that screws into a conventional artillery round thereby enabling the round to guide itself to a target. The PGK is the artillery version of the Air Force's Joint Direct Attack Munition which converted conventional bombs into smart bombs able to achieve a CEP of approximately 11 meters.¹¹ Current PGK production models have achieved a CEP accuracy of less than 30 meters at all ranges.¹² An upgraded version currently undergoing testing has achieved a CEP of 12 meters at all ranges.¹³ Cost of each Precision Guidance Kit is approximately \$10,500 with the U.S. Army and Marine Corps planning to purchase 20,864 fuzes in 2015.¹⁴ The cost effectiveness of PGK will allow a maneuver commander to attack a wider array of targets with precision strike capabilities than the more expensive Excalibur round allowed. This paper will focus predominately on how PGK might revolutionize the way artillery supports breakthrough and exploitation operations due to its relatively low cost which makes it a viable tactical weapon that can be used on a broad scale. In short, precision-guided artillery rounds offer maneuver commanders an organic fire support asset that can revolutionize offensive tactics by overcoming traditional limitations of indirect fire munitions.

History of the Defense in Depth

Before looking at how precision-guided artillery fires might revolutionize the way artillery supports breakthrough and exploitation operations, a brief review of the defense in depth

concept is required to ensure common understanding. A defense in depth is defined as mutually supporting defensive positions designed to absorb and progressively weaken an attack to a point where the defender can employ his reserves to counterattack and stop the attack.¹⁵ By giving the defense greater depth, a military could maintain a cohesive defense against the ever increasing effects of modern firepower and prevent the attacker from breaking through his defenses.¹⁶ The basic idea is that as an attacking force advanced its strength relative to the defender would decrease the further the attacker moved from his fire support, logistic bases, and command and control centers.¹⁷ While the attacker's strength decreased, the defenders strength relative to the attacker increased. This is due to the defender laying out his subsequent defensive lines with successively stronger forces as well as increasing the strength of his counterattack force with each successive line.¹⁸

The concept of defending in depth was developed by the German military during the First World War when they abandoned static defenses in favor of depth and the counterattack.¹⁹ In order to break the trench stalemate, the Allies turned to firepower, specifically artillery, to destroy enemy defenses. Extensive preparatory fires were designed to destroy located or suspected enemy machine guns, artillery units, and dug-in infantry positions prior to the ground attack.²⁰ The Germans responded to the devastating effects of artillery by adding a second defensive line outside of the attacker's artillery range as insurance against a breakthrough, thus the concept of a defense in depth was born.²¹ As the attacking force moved forward to occupy the enemy's first defensive line, they became vulnerable to successive lines of enemy artillery which were placed outside of friendly artillery range. Similarly, the defender kept his main reserves outside of artillery range and then used them to counterattack the attacking force once they had been weakened. The counterattack was usually enough to prevent a breakthrough and

gave the defense an offensive character.²² The basic concept of the defense in depth worked out by the German military in WWI has remained relatively unchanged. Similar to the German design of 1918, the keys to a modern defense are depth, reserves, and counterattack.²³

Impact on Future Breakthrough and Exploitation Operations

The intent of the preparation phase of breakthrough operations is to shape the battlefield prior to the start of the attack.²⁴ The employment of precision-guided artillery munitions will provide the ground commander the ability to attack a greater number of targets during the preparation phase while using less ammunition to achieve a greater effect, enhance the survivability of the artillery force by allowing that force to make better use of dispersion and terrain, and finally, allow limited air assets to focus on deep targets. In short, precision-guided artillery munitions will enhance the ground commander's ability to set the conditions for a successful breakthrough attack during the preparatory fires phase of breakthrough operations.

Preparation fires are defined in current artillery doctrine as a, "high volume of fire delivered over a short period of time to maximize surprise and shock effect."²⁵ The German military realized in WWI that if given enough time and ammunition, artillery can destroy almost any defensive position that can be located. The result for the Germans was to shift to a defense in depth to overcome the effects of modern firepower. The response by artillery was to shift from destruction to neutralization which allowed preparation fires to be short, violent, and intensive in order to stun the enemy long enough for the attacking force to overrun them.²⁶ It must be remembered that a defense in depth relies upon a counterattack to defeat the breakthrough attack making time a critical factor in the race between breakthrough force and the defender. By shortening the preparation fires to a few hours, the attacker hoped to achieve

surprise as well as avoid giving the enemy commander time to react.²⁷ Precision-guided artillery munitions will shorten the time required for preparation fires, thus enhancing shock and surprise.

Limitations with conventional artillery munitions require the massing of fires from multiple artillery units against a single target to achieve the desired effect in the shortest period of time. Battalions are usually the smallest unit that masses against an area target though this can be pushed down to the battery level depending on the type of target and number of rounds required to achieve the effect. The impact on future operations is that a Marine Corps division with three artillery battalions could potentially mass against only three targets simultaneously during the preparatory phase. Once those targets have been engaged, artillery forces would shift to the next three targets. Using this model it would take three artillery battalions 17 minutes to engage 27 separate targets.²⁸ In contrast, precision-guided artillery munitions use guidance to overcome the limitation of conventional munitions, thus allowing the same artillery forces to engage more targets simultaneously by using smaller firing units (battery, platoon, and even single guns). Instead of a battalion firing a “Battalion 2” at an enemy artillery battery to achieve an effect of neutralization, a single battery will be able to target the individual firing pieces of that same enemy unit, destroying the guns or rocket launchers. Assuming that the battery is the lowest unit that will fire against an enemy force with guided munitions, a Marine Division can now engage the same 27 targets in five minutes with greater effect.²⁹ If the firing unit is pushed down to the platoon level (two guns) all 27 targets could be attacked simultaneously. Use of precision-guided artillery rounds in future conflicts means that mass is no longer the key to success with artillery fires thus mitigating current concerns given U.S. forces no longer have the number of artillery pieces it had in WWII to mass against targets. In short, mass precision strikes against a greater number of targets will cause significant shock to the enemy defensive

system allowing the penetration force to move through the initial portions of a defense in depth with greater speed.³⁰

In addition to allowing the breakthrough force to attack a greater number of targets simultaneously with organic artillery assets, precision-guided artillery munitions will allow the breakthrough force to achieve greater and more predictable effects against the same targets while using less ammunition than is required with current munitions. One of the guiding principles of modern artillery is that of massing fires to ensure a desired effect is achieved.³¹ Due to deflection and range errors which cannot be completely eliminated prior to firing, a conventional 155mm artillery round fired at a maximum range of 18km can have a CEP of up to 200m. This is due to inaccuracies which increase with range. The greater the range to target the greater the probable error will be. With conventional munitions, the number of rounds fired at a target determines what effect those rounds will have on the target – suppress, neutralize, or destroy. The more rounds fired the greater the effect due to the increased probability some of those rounds will land on or near the target thus having an effect on the target. For example, it requires approximately 40 rounds to destroy a point target while only four to suppress the same target.³² Destruction usually requires rounds to actually strike the target while neutralization and suppression only require rounds land in the vicinity of the target. With precision-guided munitions a single artillery tube or rocket launcher firing a single precision-guided round will be able to hit any target whose location is known and is within range.³³ One round will be able to achieve the same effect as a battalion massing on a target with conventional munitions.³⁴ Precision gives the artillery round the relative accuracy of direct fire weapons thus allowing artillery to enter an age where it can destroy targets with relatively few precision rounds. Destruction means to damage a unit so much that it can no longer perform its

function due to massive damage to material, equipment, and significant personnel casualties.³⁵

For the future breakthrough force commander, this means less ammunition is required to be stockpiled prior to launching an attack which facilitates surprise and tempo. Similarly, due to the accuracy of precision-guided munitions, the ground commander will have higher confidence that the desired effects of preparatory fires were achieved prior to commencing the breakthrough attack. Precision fires also gives the supported commander greater latitude in striking specific capabilities within enemy units. This allows the maneuver commander for example to target the fire direction center of an artillery unit. The simultaneous attack of enemy command and control nodes, artillery batteries, and front line forces will produce a significant shock effect that will greatly enhance breakthrough operations over historical methods. Finally, precision-guided artillery rounds will produce a psychological effect on the enemy force and commander that knows as soon as it exposes itself and its location becomes known, that force will be attacked with a lethal precision strike weapon.³⁶ In short, precision-guided artillery fires will be able to open a hole for the penetrating force to maneuver through by attacking a greater number of enemy targets in a shorter time with greater effect.

Given the significant advantage enemy forces will likely have in number of artillery and rocket assets, precision-guided artillery munitions will help facilitate the survivability of friendly artillery assets across all phases of a breakthrough and exploitation operation. Due to the reduced need to mass large artillery formations against single targets due to the benefits of using precision-guided munitions, artillery forces down to the gun level will be able to disperse farther apart than historically allowed as well as take advantage of terrain in new ways that mitigate the effects of enemy counterfire. As history has shown, dispersion reduces the vulnerability of a force to the effects of fires making it harder for enemy assets to target mission essential friendly

assets. Furthermore, use of precision-guided artillery munitions means less need for artillery to be stationary firing large quantities of ammunition on an enemy target thus being vulnerable to counterfire. Finally, precision-guided munitions will allow a breakthrough forces artillery assets to shoot rapidly in a dispersed formation, move, then engage targets again from a new location.

The employment of precision-guided artillery munitions will allow for the more effective use of limited surface and air assets during breakthrough and exploitation operations. An effective breakthrough attack requires that the defense in depth be attacked in depth. This means that commanders must effectively employ surface and air assets simultaneously across the battlespace in order to set the conditions for an effective breakthrough. Unfortunately, ground commanders are increasingly reliant upon aviation assets to attack high payoff point targets such as armored forces even when those targets are within range of organic artillery units. This decision reduces the number of assets attacking deep targets in support of the breakthrough attack. The recent trend towards airpower as the predominant killing asset on the battlefield is partly due to the limitation of artillery to hit point targets as well as achieve effects greater than suppression against armored assets without expending large amounts of ammunition. Furthermore, defending forces have learned to exploit the limitations of conventional artillery, forcing ground forces to use deep strike assets in the close fight. Precision-guided artillery munitions will give the ground commander the means to achieve aircraft like effects against a wide range of located targets within artillery range. This will allow the commander to focus aviation assets once again on deep targets outside of artillery range. Attacking deep targets with aviation assets supports the breakthrough attack by slowing the defenders ability to counterattack, degrading his command and control abilities, and finally, by forcing the defender to disperse his forces to ensure survivability.³⁷ In short, precision-guided artillery munitions

enhance future breakthrough operations by allowing the commander to more effectively employ air and surface assets to attack the enemy defense in depth across its depth.

Once preparatory fires are complete and the breakthrough attack begins, the additional benefits of a more accurate artillery round will be to allow artillery forces to task organize and employ in new ways that enable it to keep pace with the mobile battle.³⁸ Keeping pace with maneuver forces has always been a challenge for artillery.³⁹ Historically, maneuver commanders have had to choose between speed or firepower while in the attack. The shrinking ability of artillery forces to keep pace with more mobile ground units has resulted in a shift towards airpower taking over the artillery role during periods of rapid forward movement through a defensive system. When airpower has been unavailable, maneuver commanders had to rely on direct fire assets to destroy enemy forces. The use of direct fire assets though tends to slow a breakthrough forces forward movement. The mobility issue is partly related to range limitations. An infantry regiment in column can be as long as 10km or half the range of a M777 artillery howitzer. This makes it difficult for the supporting artillery unit to bound artillery forces forward fast enough to maintain continuous coverage in front of the breakthrough force. Mobility is also affected by the principle of massed fires. Massed fires means that more artillery units must be stationary thereby reducing the number of units able to bound forward and keep pace with the maneuver force. Precision-guided artillery rounds will allow smaller units to provide the same support as is provided by larger artillery units today. This will reduce the requirement to mass multiple units against a single target and thus keep artillery units stationary. As such, the requirement for stationary units that can provide fire support can be pushed down to smaller sized units allowing more artillery elements to bound forward and maintain pace with and coverage for advancing breakthrough forces. For example, historically an artillery battalion

keeps two batteries in action while one moves forward. Precision capability will allow one battery to be in action while another is emplacing and the third is following in trace of the advancing force. Finally, precision-guided rounds will reduce the logistical burden of the artillery force allowing it to travel farther before needing resupply. Advancing artillery units today maintain about three days' worth of ammunition in their combat trains. Precision ammunition will reduce the number of rounds that need to be fired allowing the supporting artillery unit to advance farther with the attacking force.

Precision-guided artillery rounds will reduce the time and organic resources required to engage targets of opportunity while on the move. Though it is preferred to bypass enemy formations during a breakthrough attack when able, this is not always possible. When a target of opportunity that cannot be bypassed presents itself, breakthrough forces can either call-for-fire on the target, engage the target with direct fire weapons, or coordinate close air support against the target. Today, direct fire is usually the fastest and most accurate method, but it also exposes the attacker to enemy weapons as well as expends resources that might be needed during later stages of the breakthrough or exploitation. The employment of direct fire weapons usually results in a slowing of the breakthrough forces forward movement as it requires a force to deploy into combat formations and establish support by fire positions. Close air support is not as responsive as organic fires, and as mentioned earlier, is not the best use of limited air assets when other means are available. Calling-for-fire on a target of opportunity today requires a trained observer and usually entails adjusting fire onto the target before a fire-for-effect can be initiated. Adjusting fire means loss of surprise and tempo. Furthermore, not every unit has a Forward Observer present to call-for-fire. Precision-guided artillery rounds will allow even untrained observers to get first-round effects on a target reducing the need for trained observers

across the force. Any unit with a laser range finder that can precisely locate a target will be able to initiate a call-for-fire with first round effects. In short, precision-guided artillery munitions will allow a rapidly moving force to leverage current technologies to quickly locate and engage targets with great effect, thus allowing the attacking force to avoid the need to suppress or maneuver against an unforeseen enemy force or target. This means greater tempo for the breakthrough force.

Precision guided artillery rounds can reduce the historical complexity of modern combat by assisting the breakthrough force in overcoming the challenges associated with suppression.⁴⁰ Reducing the complexity of breakthrough operations allows the attacking force to maintain a higher tempo through a defensive system. Suppression, along with dispersion and combined arms, is a means for overcoming the lethality of modern weapons.⁴¹ Suppression allows an attacking force to move around a target or keep their heads down while another forces maneuvers into a position to kill them.⁴² To be effective, suppression must be maintained long enough for the attacking force to close on the enemy but stop before friendly forces begin to take casualties from friendly fire.⁴³ This requires potentially large amounts of ammunition to maintain the suppression and tight coordination between multiple units on the move.⁴⁴ The accuracy of precision-guided artillery munitions allows the attacker to place a suppression round directly on a target that needs to be suppressed without having to fire the traditional mass of rounds with a widely dispersed pattern at the target. The greater accuracy will allow the maneuver force to maneuver closer to the target before the suppression stops since the effect of the round can be controlled and accurately predicted. Finally, the accuracy of precision-guided munitions will give artillery the ability to destroy fixed targets as well as armored targets that it has historically been only able to suppress. This will reduce the requirement for a penetration

force to suppress the target while another force moves in for the kill. If the target can be destroyed without the need of the attacking force to maneuver on the target, then the attacking force can continue its forward movement.

Conclusion

Historically, technology has not been a good predictor of success in combat.⁴⁵ But it has often resulted in a shift of the relative advantage of the offense over the defense or vice versa.⁴⁶ The development of precision-guided artillery munitions by itself will not fundamentally improve the chances an attacking force has of breakthrough a defense in depth. This new technology must be matched with a corresponding change in the way forces are employed to penetrate a defense in depth.⁴⁷ This paper has attempted to show how precision-guided artillery munitions can change the way artillery forces support breakthrough operations and what effect more accurate artillery munitions will have on ground maneuver. The operational impact of precision-guided artillery munitions on future breakthrough and exploitation operations can be summarized as 1) An increased ability to create rapid and precise effects throughout the battlespace from a flexible and networked artillery force, 2) Enhanced speed and operational reach of the breakthrough force, and 3) More effective use of limited surface and air assets. The conclusion of this paper is that precision-guided artillery munitions will change modern artillery tactics which will enable the next evolution in breakthrough and exploitation operations. In short, it is new tactics enabled by new technology that will provide the next evolution in overcoming the ever-increasing firepower associated with the modern defense.

Before the U.S. military can explore new methods of penetrating a defensive system, a paradigm change must occur. Without the associated paradigm change the military will continue to look for means of making modern technology support old tactical methods.⁴⁸ First, the

military must envision a battlefield in which it does not have complete air superiority or the ability to attack enemy forces at will with massive airpower. If one assumes that air superiority is a given in future conflicts, there is little reason to search for or develop new tactics that take advantage of new technology. Secondly, the belief that artillery is best when employed to neutralize vice destroy must change. Historically artillery could only destroy when large amounts of ammunition were expended.⁴⁹ In the future artillery will be able to destroy point targets with one or two rounds of precision ammunition. This will reduce the complexity of the attack and allow an attacking force to maximize its speed as it punches through a defense and exploits. Finally, U.S. forces must change how it thinks about the principle of massed fires. Historically this has meant large artillery forces firing at a single target in order to achieve a desired effect. In the future this will mean a large artillery force firing at numerous targets simultaneously in order to achieve surprise and possibly shock against an enemy's defensive system. The principle of massed fires drives how artillery organizes and deploys for combat which hasn't changed much since WWI. Guided artillery munitions will have a profound impact on how artillery organizes and is employed in support of future breakthrough and exploitation operations.⁵⁰ It will give the supported commander increased flexibility in how he positions his forces and task organizes them for combat. Precision artillery munitions are a significant advance as to require new tactics, organization, and a cultural change in the artillery community in order to improve upon the current methods for conducting breakthrough and exploitation operations.⁵¹ In short, we should not wait until the next conventional war to alter our tactics for breakthrough and exploitation operations.

Notes

¹ Bruce Berkowitz, *The New Face of War: How War Will Be Fought in the 21st Century* (New York: The Free Press, 2003), 77.

² Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, New Jersey: Princeton University Press, 2004), 43.

³ Jonathan B. A. Bailey, *Field Artillery and Firepower* (Annapolis, Maryland: Naval Institute Press, 2004), xix.

⁴ Howard L. Ware III, "Will the King of Battle Reign on the Future High Intensity Battlefield?" (masters thesis, School of Advanced Military Studies, 1989), 20-23.

⁵ Ware, 19.

⁶ James C. Lewis, "The Future Artillery Force Today: On the Horizon Changes for Artillery," *Marine Corps Gazette* 90, no. 7 (July 2006): 24.

⁷ Berkowitz, 78.

⁸ Carlo Kopp, "Artillery for the Army: Precision Fire With Mobility," *Defense Today*, 15. <http://www.ausairpower.net/SP/DT-SPH-0705.pdf>.

⁹ John Halvey and Stefan Blomgren, "Precision Fires for the Field Artillery." (PowerPoint presentation, 2005). <http://www.dtic.mil/ndia/2005garm/thursday/blomgren.pdf>.

¹⁰ <http://www.defenseindustrydaily.com/atks-pgk-turning-shells-into-precision-artillery-07430/>

¹¹ http://en.wikipedia.org/wiki/Joint_Direct_Attack_Munition. A JDAM costs approximately \$27,000 each.

¹² Peter J. Burke, "XM1156 Precision Guidance Kit (PGK) Overview," (PowerPoint presentation, 12-13 May 2010). <http://www.dtic.mil/ndia/2010fuze/IVAPergolizzi.pdf>.

¹³ <http://www.defenseindustrydaily.com/atks-pgk-turning-shells-into-precision-artillery-07430/>

¹⁴ The US Army and Marine Corps ordered 1,332 Excalibur rounds in 2014. In comparison, the US Army and Marine Corps plan to buy 20,864 Precision Guidance Kits in 2015. The US Marine Corps 11th Marines Artillery Regiment fired 11,800 conventional rounds during the two week invasion of Iraq in 2003.

¹⁵ Bailey, 560.

¹⁶ Timothy T. Lupfer, "The Dynamics of Doctrine: The Changes in German Tactical Doctrine During the First World War," *Leavenworth Papers*, no. 4 (July 1981): 3.

¹⁷ Lupfer, 12.

¹⁸ Lupfer, 12.

¹⁹ Biddle, 32.

²⁰ Lupfer, 2.

²¹ Lupfer, 3.

²² Lupfer, 16.

²³ Biddle, 46.

²⁴ David T. Zabecki, *Steel Wind* (Westport, Connecticut: Praeger Publishers, 1994), 105.

²⁵ Headquarters, Department of the Army, *Field Artillery Operations and Fire Support*, FM 3-09 (Washington DC: HQDA, June 2014), 1-5.

²⁶ Zabecki, 34.

²⁷ Zabecki, 105.

²⁸ This example assumes that it takes a "Battalion 2" (each gun in the battalion firing two rounds at the same target) to achieve the desired effect. The sustained rate for artillery is two rounds per minute. It takes one minute to shift from one target to another. Thus, a battalion could fire two rounds at Target 1 in one minute and then require another minute to shift to Target 2. A battalion could thus engage nine targets in 17 minutes given best case situation.

²⁹ Given the precision of PGK rounds, a six gun battery can effectively hit all six guns of an enemy battery with a “Battery 2” (each gun firing 2 precision rounds at an individual artillery piece) thus destroying the fighting capability of that unit. The same firing timeline as the previous example still applies (2 rounds a minute, 1 minute to shift to a new target).

³⁰ Vincent R. Bielinski, “Massed Precision Fires—A New Way of Thinking,” *Field Artillery Journal* (March-April 2009), 13.

http://sill-www.army.mil/firesbulletin/2009/Mar_Apr_2009/MAR_APR_2009_Pages13_14.pdf.

³¹ *Field Artillery Operations and Fire Support*, 1-6.

³² Biddle, 37.

³³ Berkowitz, 77.

³⁴ Bielinski, 13.

³⁵ *Field Artillery Operations and Fire Support*, 1-3.

³⁶ Berkowitz, 77.

³⁷ Biddle, 62.

³⁸ Bailey, 265.

³⁹ Bailey, 254.

⁴⁰ Biddle, 38.

⁴¹ Biddle, 38.

⁴² Biddle, 37.

⁴³ Biddle, 38.

⁴⁴ Biddle, 38.

⁴⁵ Biddle, 24.

⁴⁶ Biddle, 15.

⁴⁷ Biddle, 28.

⁴⁸ Zabecki, 146.

⁴⁹ Biddle, 37.

⁵⁰ Bruce Gudmundsson, *On Artillery* (Connecticut: Praeger Publishers, 1993), 143.

⁵¹ Bradley J. Meyer, “The Breakthrough Battle” (Unpublished paper, August 2008), 4.

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