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Technology Wargaming Implementation Office (SAAL-ZT)

Envisioning the Deep Future of Small Arms 2022-2042

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Executive Summary

In the summer of 2012, HQDA G3 provided a presentation to the Chief of Staff of the Army (CSA) focused on small arms overmatch at the squad level. This presentation resulted in questions raised by the CSA regarding the nature of the Army's holistic strategy for small arms dominance into the future. HQDA G3 received the task to follow up on these questions and present back to the CSA a comprehensive small arms strategy. In support of the HQDA G3 mission, ASA(ALT) SAAL-ZT as the responsible agent for the Army's science and technology investments, agreed to identify and prioritize future concepts with potential to enable long-term small arms overmatch for US military forces from the period 2020-2040+.

ASA(ALT) SAAL-ZT identified the following key questions to address through this activity:

- What technological and other trends, to include changes in the threat environment, will influence the evolution of small arms over the mid to far term given the need for emerging/new technology to remain under development longer in order to reach a higher Technology Readiness Level (TRL) before seeking transition to a program executive office (PEO)?
- Given these trends, what future small arms technology concepts are possible in 2020-2030 and 2030-2040 under various scenarios?
- How would the capabilities provided by these future small arms technology concepts support a variety of alternate future scenarios?
- What S&T investments are needed to realize these future small arms technology concepts?

ASA(ALT) SAAL-ZT reached out to the United States Military Academy's (USMA) Network Science Center and to the Natick Soldier Research, Development and Engineering Center (NSRDEC) to lead the team that would address these questions. The study team took a comprehensive approach to looking into the future of small arms that encompassed several key thrusts:

- An analysis of the history of small arms technology within the US Army, from the Revolutionary War through recent operations in Iraq and Afghanistan.
- Interviews with experienced commanders at the platoon/company, battalion, and brigade/division level.
- Development of a set of alternate futures that describe potential scenarios for the strategic and tactical environment from 2022-2042.
- An ideation exercise that used the alternate futures and emerging insights from the other study thrusts to ground a free-thinking exploration of conceptual technologies for small arms in 2022-2042.

This process yielded numerous insights into the role of small arms technology in enabling squad overmatch in 2022-2042:

Lessons for the Future from the History of US Army Small Arms

- Technological overmatch is part of a complex system that requires simultaneous coordination on many fronts.
- Technological overmatch can be denied by Institutional Inertia.
- Technological overmatch is transient.

Insights into the Strategic and Tactical Environment of 2022-2042

- The definition of "technological overmatch" will change dramatically over the next 30 years
- It is impossible to discuss technological overmatch without considering rules of engagement

Insights into Future Technologies for Small Arms

- Future small arms technologies will blur established “lanes” within the S&T and PEO/PM community
- Emerging technologies promise to radically change the nature of how we define the relationship between Soldiers and small arms. In particular, robotic platforms and exoskeletons could provide disruptive capabilities for squads that address many limitations of current systems. However, these technologies will increase the "footprint" of the squad, with implications for the design of air assault and ground vehicles
- Few of the concepts provided overmatch across all alternate futures

Insights into the Nature of Innovation in Army S&T

- The Army has a rich tradition of small arms innovation, including many concepts that arrived "before their time". These represent a significant, largely untapped resource.
- Innovation is an inherently human exercise dependent on "hot teams" given time and space to think big.
- Ideation must become a routine business practice for Army S&T.

This report details the methods that were employed in this study and discusses the points noted above in detail. Based on the insights gained from the study several recommendations are made to ASA(ALT) and Army G3. The study team recommends:

- That the Army G3 lead a deep consideration of how the Army should define, and more importantly, measure overmatch in the future. The development of new measures of effectiveness/measures of performance for overmatch in small arms is essential to guide research and development of new small arms systems.
- That ASA(ALT) portfolio leads work with TRADOC, HQDA, and SOCOM (collectively comprising the small arms requirements Community of Interest (CoI)) as well as USMC and others to develop an architecture for small arms to baseline current investments and guide future S&T activities.
- That ASA(ALT) work with DARPA and the S&T Enterprise to determine the state of the art in exoskeleton-related technologies and whether a TECD or ATO-level program should be funded to develop these systems. Furthermore, we recommend that ASA(ALT) leads an ongoing dialog between TRADOC and the S&T community to ensure that the revolutionary capabilities of an exoskeleton are matched with appropriate developments in doctrine and materiel requirements.
- That ASA(ALT), the CoI, and the intelligence community collaborate on a “deep dive” into the potential disruptive effects of squad robotics as a small arms platform to: a) roadmap the technologies that are feasible and b) prepare for the doctrinal, organizational, and acquisitions changes that will be driven by the robotics revolution that will spread from the air to the ground.
- That ASA(ALT) continue to engage with the CoI and other thought leaders in future operations to articulate the demand signals that will drive future small arms needs and that the S&T portfolio be reviewed regularly against these projections to ensure that the strategy for small arms technology development remains adaptive to future trends.
- That ASA(ALT) and the S&T Enterprise leadership investigate how the capabilities of the Federal Research Division of the Library of Congress could be leveraged to enhance the Army’s corporate knowledge of innovative small arms concepts from the past that could be worth revisiting today.

- That ASA(ALT) work with the CoI and the S&T Enterprise to develop a regular process for conducting structured ideation activities that are grounded in threat and mission projections and that utilize sound analytical methods to encourage the transition from ideas "on the drawing board" to new S&T programs.
- That ASA(ALT) lead a deep and comprehensive look at the 6.1 and 6.2 components of the small arms S&T portfolio and ask hard questions about whether our investments in future small arms technologies align with the forces that are shaping future operational needs. In leading this strategic conversation we encourage ASA(ALT) to engage individuals and organizations outside the traditional centers of mass involved with Army small arms science and technology. In thinking about the deep future it is essential to bring in perspectives well outside the box (and the beltway).

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List of Acronyms

AEF - American Expeditionary Force
AFRICOM - Africa Command
AFV - Armored Fighting Vehicle
ARCIC – Army Capabilities Integration Center
ARDEC - Armament Research, Development and Engineering Center
ARL - Army Research Laboratory
ASA(ALT) - Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
ASD(R&E) – Assistant Secretary of Defense for Research and Engineering
ASEAN - Southeast Asian Nations
ASIRS – A Study of the Infantry Rifle Squad
ATGM - Anti-Tank Guided Missile
ATO – Advanced Technology Objective
AVATAR - Advanced Virtual Autonomous Tethered Assault Robot
BAR - Browning Automatic Rifle
CAD - Computer Aided Design
CCP - Chinese Communist Party
CDTE - Counter Defilade Target Engagement System
CGSC – Command and General Staff College
CLAWS - Combat Lightweight Automatic Weapon System
CNG – Compressed Natural Gas
CoI – Community of Interest
COTS - 1. Commercial Off the Shelf 2. Commercial Orbital Transportation System
CSA - Chief of Staff of the Army
CTA – Collaborative Technology Alliance
DARPA – Defense Advanced Research Projects Agency
DE - Directed Energy
DENI - Directed Energy Negation and Integration
DOTMLPF - Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities
DST - Decision Support Tool
DTIC - Defense Technical Information Center
EBR – Enhanced Battle Rifle
EM - Electromagnetic
EU - European Union
FAKE - Flabbergasting Armament Kinetic Employer
FASTNet - Future of Army Science and Technology Network
FID - Foreign Internal Defense
FRD - Federal Research Division
FY - Fiscal Year
GAP - Genius Ammunition Project
GDP - Gross Domestic Product
GSS - General Social Survey
HE - High Explosive
HEPA - Hyper Energy and Power Ammunition
HERO – Holographic Environment Radius Operations
HOPE – Hyperbolic Operations Projector-Experimental
HQDA - Headquarters, Department of the Army
IED – Improvised Explosive Device
IQ – Intelligence Quotient
IR - Infrared
IRUS - Infantry Rifle Unit Study
ISR - Intelligence, Surveillance, Reconnaissance

ISS - International Space Station
JCIDS - Joint Capability Integration and Development System
JIEDDO – Joint Improvised Explosive Device Defeat Organization
JSSAP - Joint Services Small Arms Program
KE - Kinetic Energy
LAW – Light Anti-Tank Weapon
LNG – Liquefied Natural Gas
MANPADS - Man-Portable Air Defense Systems
MAPS – Military Artificial Proxy Soldiers
MCCDC – Marine Corps Combat Development Command
MCoE – Maneuver Center of Excellence
MCWL – Marine Corps Warfare Laboratory
MEMS – Micro Electro-Mechanical Systems
MENA – Middle East and North Africa
METT-TC – Mission, Enemy, Terrain and Weather, Troops and Support Available, Time Available, Civil Considerations
MOS - Military Operational Specialty
MRAP – Mine-Resistant Ambush Protected
NASA - National Aeronautics and Space Administration
NATO - North Atlantic Treaty Organization
NGO – Non-Governmental Organization
NRO - National Reconnaissance Office
NSRDEC - Natick Soldier Research, Development and Engineering Center
NVESD – Night Vision Electronic Sensors Directorate
OCRSP - Optimum Composition of the Rifle Squad and Platoon
ODASA(R&T) – Office of the Deputy Assistant Secretary of the Army for Research and Technology
ODIN – Observe, Detect, Identify, Neutralize
OEF - Operation Enduring Freedom
OIF - Operation Iraqi Freedom
ONR – Office of Naval Research
OPSEC – Operations Security
OPTEMPO - Operational Tempo
OT&E – Operational Test and Evaluation
PEO-Soldier - Program Executive Office - Soldier
PGM – Precision-Guided Munition
PLA - People's Liberation Army
PM - Program Manager
PM-MAS – Program Manager Maneuver Ammunition Systems
POM - Program Objective Memorandum
PREP – Personal Rocket Explosives Project
R&D - Research and Development
RDECOM - Research, Development and Engineering Command
RMA – Revolution in Military Affairs
ROE – Rules of Engagement
RPG – Rocket-Propelled Grenade
RSPEP - Rifle Squad and Platoon Evaluation Program
S&T - Science and Technology
SARP – Small Arms Repair Parts
SAVE - Soldier Asymmetric Vision Equipment
SAW - Squad Automatic Weapon
SLACK - Squad Level Active Collaborating Knowledge
SMG – Sub-Machine Gun
SOCOM - Special Operations Command

SOF - Special Operations Forces
SpaceX - Space Exploration
SWEAT - Soldier, Weapon, Ammunition, Enablers, Training
SWORDS – Special Weapons Observation Remote Recon Direct Action System
TECD – Technology Enabled Capability Demonstration
TISO – Threat Integration Support Office
TRADOC - Training and Doctrine Command
TRL – Technology Readiness Level
UAV - Unmanned Aerial Vehicle
UCAV - Unmanned Combat Aerial Vehicle
UK – United Kingdom
UN - United Nations
USAF - United States Air Force
USAMU – US Army Marksmanship Unit
USMA - United States Military Academy
USMC - United States Marine Corps
USN - United States Navy
VTC – Video Teleconference
VTOL - Vertical Take-off and Landing
WASP - Weaponized Assault Surveillance Platform
WISH - Weapon Informatics Soldier-human
WMD - Weapons of Mass Destruction

Whatever happens, we have got
The Maxim gun, and they have not[1].

Hilaire Belloc, "The Modern Traveller", 1898

Introduction

In the summer of 2012, HQDA G3 provided a presentation to the Chief of Staff of the Army (CSA) focused on small arms overmatch at the squad level. This presentation resulted in questions raised by the CSA regarding the nature of the Army's holistic strategy for small arms dominance into the future. HQDA G3 received the task to follow up on these questions and present back to the CSA a comprehensive small arms strategy. In support of the HQDA G3 mission, ASA(ALT) SAAL-ZT as the responsible agent for the Army's science and technology investments, agreed to identify and prioritize future concepts with potential to enable long-term small arms overmatch for US military forces from the period 2020-2040+.

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- An ideation exercise that used the alternate futures and emerging insights from the other study thrusts to ground a free-thinking exploration of conceptual technologies for small arms in 2022-2042.

The first thrust entailed a broad look at the history of small arms technology within the US Army, from the Revolutionary War through recent operations in Iraq and Afghanistan. As with many defense issues the past is a prologue. The future development of small arms technology is deeply embedded in the institutional history of the Army that has shaped views on the role of small arms and the individual rifleman. Furthermore, the history of

[1] Belloc's couplet underscores the transient nature of technological overmatch. While the Maxim gun gave the British tremendous overmatch against native forces in the colonial wars of the late 19th century, changes in tactics and widespread adoption of the machinegun by other European powers soon leveled the playing field.

technology adoption by the US and other military forces provides instructive lessons on barriers to innovation that will persist into the future. This historical analysis was used to inform the development of alternate futures and to shape the ideation exercise described below. The key insights are presented below. In addition, Appendix A provides an extended discussion of evolutions and revolutions throughout the history of small arms development.

The second thrust involved interviews with experienced commanders at the platoon/company, battalion, and brigade/division level. The purpose of these interviews was to take the pulse of those who have led men under fire and understand their view of current Army small arms, the role of small arms in shaping leadership decision-making, and how today's leaders wish tomorrow's Soldiers to be armed. These leaders provided a wealth of practical insights into the role of small arms on the battlefield that informed development of the alternate futures and established context for the ideation exercise.

The third thrust was the development of a set of Alternate Futures that describe potential scenarios for the strategic and tactical environment from 2022-2042. One of the challenges in conceiving future technologies is that the value of a particular concept depends on how the security environment evolves. The kind of small arms that make sense in a future dominated by low-intensity, stability operations in urban environments could be quite different than the kind of small arms that would be needed to fight a large-scale ground war against a near-peer nation state. On the other hand, there could be concepts that make sense across a range of potential future scenarios. These are particularly promising from an investment standpoint as they afford flexibility in the face of an uncertain future. Of course, it is impossible to make precise and accurate predictions of the future 30 years out. Instead, many forward-looking organizations develop a set of "alternate futures" that capture a range of possibilities for how the future might unfold. Within industry this approach is referred to as scenario planning. An alternate future is a narrative describing one possible path the future might take based on a set of key drivers, or critical uncertainties. A set of futures can be developed around different scenarios for how the critical uncertainties resolve. For example, given that we are uncertain about the specific missions squads will perform in 2042, we could design a set of scenarios that captures a range of possibilities informed by data, doctrine, and strategic thought. The futures provide "sandboxes" for thinking about technology in a structured and rigorous way. Using alternate futures also helps ground ideation and mitigates risks common to generating technology concepts. For example, during group ideation settings it can often happen that participants advocate for "pet projects" – playing those ideas against a set of futures helps assess whether an idea stands on its merits. Another pitfall in ideation is that participants can get carried away with a "cool" technology that has exciting scientific and technical implications. Returning to a set of alternate futures helps ensure that these flights of fancy remain linked to capabilities Soldiers and squads might actually need. Appendix B presents the four futures that were developed for this study and the methods that were used to develop them[2].

The fourth and culminating thrust was an ideation exercise designed to bring together experts from across the technical and tactical community to generate concepts for future small arms technologies that would be feasible in the 2022-2042 time frame. This exercise employed ideation techniques developed by the Natick Soldier RD&E Center (NSRDEC) and resulted in 20 concepts for future small arms technologies that ranged from radical innovations in the Soldier-weapon interface to disruptive ideas for offloading the physical and cognitive burdens of shooting to robotic platforms (while retaining Soldier fire control). While the individual concepts provided helpful signposts for promising technologies the Army could pursue, the insights that emerged during the exercise from the distinguished group of experts that participated point to a set of looming decision points that could fundamentally affect investments in future small arms technologies. These insights are discussed below. Details of the methods used at the ideation exercise are presented in Appendix C. The concepts that were generated are presented in Appendix D.

[2] As a product of the analysis of the results the exercises using these four futures, a hybrid or "surprise free" scenario was developed for consideration during possible follow-on exercises.

The remainder of this report will discuss the major insights that emerged from this study on the future of Army small arms. Recommendations are also provided on actions the Army could take to increase its ability to generate and capitalize on innovative small arms technology to maintain overmatch into the future.

Lessons for the Future from the History of US Army Small Arms

Key Insights

- Technological overmatch is part of a complex system that requires simultaneous coordination on many fronts.
- Technological overmatch can be denied by Institutional Inertia.
- Technological overmatch is transient.

Technological overmatch is part of a complex system that requires simultaneous coordination on many fronts.

Technological overmatch is not simply a product of having better technology. The technology must be adequately supported in terms of both maintenance and logistics, it must be part of a coherent and effective doctrine, and there must be a training regime to mold the end user into the doctrinal context of the technology. Without this total coordination, the overall effectiveness of the technology will be reduced.

History provides many examples of the systems nature of technological overmatch. For instance, while breech loading and rifling would have offered significant overmatch for British forces during the American War of Independence their Army rejected a functional breech-loading rifle. The Ferguson Rifle, manufactured by Major Patrick Ferguson, was an exceptional weapon that offered fast (by the standards of the day) and accurate fire. Adoption of the Ferguson rifle would have given the British a significant asymmetry in firepower against the colonists, but the difficulty of its manufacture led military leaders to turn down the design. Simply put, the logistical and manufacturing base of the 18th century could not support an innovative technology. [3]

While the tale of the Ferguson rifle shows how the potential of revolutionary technologies can be constrained by manufacturing context, a more famous example, that of the Maxim Gun, relied significantly on its doctrinal and employment contexts. While most stories of the dismissal of the Maxim gun before World War I are questionably authentic, certainly the doctrines of the French and British Armies had not been adapted to make the most use of the new weapons. It certainly is not the case that they were unfamiliar with these machineguns, as they had found significant use in the rampant colonial wars of the late 19th century. However, western armies did not recognize the revolutionary nature of the Maxim gun until it made their doctrine just as vulnerable as that of their colonial opponents. [4]

[3] This was the argument used by the Union's department of ordnance during the Civil War to not rapidly convert from the rifled musket to the repeating Spencer carbine and the Henry rifle.

[4] Very few professional military thinkers and planners before the "Great War" foresaw the potential battlefield consequences of the late nineteenth century technological revolutions in small arms and rapid fire artillery using high performance fragmenting ammunition. A noteworthy exception to the rule was the writings of Ivan Stanislavovich Bloch (Blioch) who might well be viewed as the under-appreciated father of military operations

Western armies did not recognize the revolutionary nature of the Maxim gun until it made their doctrine just as vulnerable as that of their colonial opponents.

The same illustration can be drawn from the Second World War with comparative performance of American and German combat squads. While the American squads were armed with the Garand M1 Rifle, which was far superior to the Mauser K98 bolt action that the German infantry had, the German squad had a machinegun as organic fire support. In addition, the German doctrine was built around the machinegun's firepower, with the riflemen serving to protect and sustain the MG34 or MG42 within the squad. This doctrinal difference meant that although in theory the US Soldiers had a significant technological overmatch in terms of their battle rifles, the Germans often had an edge due to their doctrine, organization, and insistence on integration of automatic fire at the squad level.[5]

It is also important to recognize that an overly vigorous short-term focus on "revolutionary" or "disruptive" technologies can undermine appreciation for humble technologies that enable cascading innovations. The development of the metallic cartridge provides an instructive example. Metallic cased ammunition was part of a larger, slower development through paper cartridges[6], percussion caps, the Minie ball[7], and finally it emerged as the complete metallic cartridge. The metallic cartridge itself, while more reliable and stable than paper versions, was not in isolation a dramatic technological improvement over premade paper cartridges.[8] However, the metallic cartridge did not exist in isolation- instead it proved to have synergistic effects with almost every concurrent military evolution or revolution in turn. Metallic cartridges allowed for reliable automatic fire[9], made breechloaders practicable, made magazine rifles effective, and proved to be extremely beneficial to logistical services. In short, they not only proved an effective improvement on the previous design, they enabled a wide range of extremely important changes of the military tactical and operational art in their own right.

Technological overmatch can be denied by institutional inertia

While technological overmatch is always the goal, the development and adoption of new technology happens within a system that often places most of its faith in currently used technology. Simply put, large-scale change and adoption is difficult, often expensive, and requires the alteration of entire systems of logistical, tactical, and strategic planning. Innovative technology, even that which can lead directly to overmatch, is often ignored or outright rejected within many military systems until its adoption by one competitor later creates the impetus for change within other military systems.

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research. See Ivan Stanislavovich Bloch and T. Steed, Is War Now Impossible? An Abridgement of The War of The Future In Its Technical, Economic, and Political Relations (1899), Kessinger Publications 2008.

[5] Of course on an even larger level it was the effective logistical base and extremely coordinated combined arms capabilities of the Americans that spelled doom for the German Wehrmacht, showing that the system of technological overmatch goes well beyond the small arms on the modern battlefield.

[6] Paper cartridges were initially a paper wrapper filled with gunpowder, wadding, and the ball ammunition which would be torn and emptied into a muzzle-loading weapon. Later these could be formed and have a percussion cap in them, such as for use with the Dreyse Needle-Gun.

[7] The Minie Ball (or Minie Bullet) was a conical bullet with a concave end that mushroomed upon firing. This allowed the bullet to be narrower than the rifled barrel for ease of loading but then still fit into the grooves for the effect of the rifling upon ignition. This innovation has the additional attraction of allowing contemporary armies to convert their inventory of muskets into rifled muskets with dramatically increased lethality.

[8] In fact, the paper cartridge using Chassepot rifle of the French army was only slowly adapted to the metallic cartridge later (the version of the Chassepot which was modified to use metallic cartridges was renamed the Gras Rifle). Interestingly, the recent explorations into caseless ammunition may be bringing the concept and advantages of the paper cartridges back into vogue, albeit with more modern materials.

[9] The early Gatling Gun used paper cartridges, but was notoriously unreliable.

Historically this pattern is extremely well established. While rifled muskets had been available since at least the early 18th century,[10] their widespread adoption was not accomplished until the mid-19th century despite their clearly superior range and accuracy. Their adoption was stymied by the institutional barriers of manufacturing, greater emphasis being placed on rapidity of fire[11], and even the tactical doctrine that rejected the necessity of longer-ranged and accurate fire.[12] It was not until the extremely effective use of rifles on the larger European battlefields[13] and the introduction of the Minie Bullet[14] that they rifles were accepted on a widespread basis.

Perhaps the most prevalent modern example of this phenomenon manifested during the Cold War. While the Soviet Union oversaw the production of the Kalashnikov designed assault rifle with lower power ammunition[15] that eventually became the AK47, the United States maintained its institutional and doctrinal focus on battle rifles with full power ammunition for the infantryman. While the Warsaw Pact and its clients transitioned to assault rifles as the standard small arm for their infantry,[16] the United States stayed insistent on the semiautomatic rifle using a full power cartridge as the weapon of choice. This was founded on a number of reasons, ranging from the worry that an automatic weapon would cause a Soldier to waste all of his ammunition to the insistence that the American Soldier was first and foremost a rifleman whose role was to project a single, large grain bullet accurately far downrange. As such, in 1959 the United States produced the M14 Battle Rifle as its standard armament.[17] This refusal to adopt an assault rifle would be maintained until the Vietnam conflict, where it was discovered that the doctrine that the M14 supported was mismatched to both the conflict and its opposing weapons system.[18] The United States finally adopted the M16 in 1963, joining the Soviet Union and its allies in using an assault weapon nearly a full decade and many lives later.[19]

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[10] Hunting pieces in the 18th century known as Snaphounces used rifling for accuracy and these were used often in the skirmishing wars of the colonial frontiers. The rifle was accepted as such a necessary weapon in these conflicts that they appear far more often in them. Major Ferguson's rifles were famed for their firepower and accuracy but were not adopted despite their efficacy. The Kentucky Rifle (or Pennsylvania Rifle) played a decisive part in the frontier struggles and the later battle of Saratoga in the American Revolution.

[11] King Frederick II of Prussia placed weight and rapidity of fire as the cardinal virtue for linear warfare. His successes in the Silesian Wars and the Seven Years War solidified his tactical thinking as the standard within Europe.

[12] Napoleon Bonaparte famously rejected the usage of rifles even for his skirmishers, noting that the slowness of the fire was a liability and that his column tactics made such range unnecessary.

[13] The effectiveness of such formations as the 95th Rifles of the British Army, the Austrian *Grenzer*, and the Prussian *Jaegers* during the Napoleonic conflicts helped highlight the advantages of the rifle, although it remained a specialist weapon.

[14] See footnote above.

[15] Late in the war, the Germans began to replace their Mauser rifles with the Schmeisser designed StG-44 Strumgewerhr (assault rifle) using the 7.92x33mm short round was the basis for the Kalashnikov AK47 that become the standard infantry weapon in the Warsaw Pact during the Cold War. This represented the major design and conceptual break from the bolt action and semi-automatic rifles equipped with full power rifle ammunition.

[16] Belgium created the FN FAL, England the L1A1, and West Germany the G3 were the contemporaries of the M14 that used the full power 7.62x51mm ammunition that had become the NATO standard..

[17] This was a full 3 years following exposure to the AK47, which was first revealed on a large scale during the Hungarian Uprising of 1956.

[18] The UK developed the EM1 Jason 6.25x43mm "bullpup" assault rifle in 1951 which fell out of favor after NATO standardized on the 7.62x51mm ammunition, and the British Army adopted the compatible FN FAL design. The bullpup design in the form of the SA-80 5.56x45mm assault rifle was adopted by the British Army in the late 1980s.

[19] During the Cold War, the Warsaw Pact reinforced their AK47 equipped squads with deployment of the PK light machine gun and the rocket propelled grenade (RPG), the latter a direct descendent of the German Panzerfaust RPG. This was the combination that gave the North Vietnamese firepower parity if not overmatch against US ground forces at the squad and platoon echelon during the Vietnam War.

From the perspective of the development of the full power cartridge with smokeless power and bolt action rifle during the late nineteenth century, it is noteworthy how long the US stayed with the concept of rifle squad with similar armament. In fact, the concept of the assault rifle using smaller and high velocity ammunition did not displace the M14, the final full power combat rifle, until well into the Vietnam War. This delay in shifting to the German developed assault rifle concept was due in part to the power of doctrinal and institutional resistance to change the concept of the basic rifleman. During this period there was little innovation in the development of body armor other than the introduction of a new steel helmet during World War II. Body armor relying on steel plates saw very limited use up through the Vietnam War. Prompted by the results of the Vietnam War with the Vietnamese forces gaining a measure of overmatch at the squad and platoon level echelon of combat, the US Army developed and deployed the Squad Automatic Weapon (SAW), the Bofors M136 (AT-4) 84mm disposable light anti-tank weapon (LAW)[20], and a first generation of Kevlar helmets and body armor. Other new Soldier enablers emerged by the mid-1980s with the introduction of night vision and laser range finders. Aside from a greatly expanded investment in training and simulation technology, the cost of fielding an early 21st century trooper is now substantially greater than a trooper of the Vietnam War era.[21] This trend in the investment of enablers other than a new generation of small arms is likely to continue and may accelerate substantially during the period of this forecast (2022-2042).

Technological overmatch is transient

Technological Overmatch and can does occur throughout history- however, in the oppositional relationship involved in military technology, any overmatch is analyzed by the disadvantaged party and either adoption or countermeasures are immediately taken to nullify this advantage. The efforts at adoption or nullification are often directly proportional to the degree of overmatch the new technology offers. If the new technology is a minor evolutionary change, the impetus for adoption is less due to the lack of decisive effect. If the technology is revolutionary, it demands adoption or nullification as the only alternatives to defeat[22]. Regardless, overmatch is and always will be a temporary condition.

Historical examples are rife. In terms of overmatch that quickly had to be adopted, we essentially see any universal current small arms technology. Rifling, while initially viewed as a luxury or even a hindrance, was universally accepted amongst European and American armies by the 1840s. Metallic cartridges were initially

[20] Replacing the lighter but less effective M72 66 mm Vietnam era LAW.

[21] For an analysis of the cause of combat casualties during Operation Iraqi Freedom/ and Operation Enduring Freedom (OIF/OEF) see LTC Philip J. Belmont Jr., MD, Major Andrew J. Schoenfeld, MD, and Captain Gens Goodman, DO, "Epidemiology of Combat Wounds in Operation Iraqi Freedom and Operation Enduring Freedom: Orthopaedic Burden of Disease", *Journal of Surgical Orthopaedic Advances*, Volume 10, Number 1, Spring 2010. This analysis is consistent with the historic trend since the Civil War that small arms projectiles have become increasingly displaced by explosive means such as artillery, mortars, and IEDs as the dominate source of combat casualties. Further, this analysis highlights the critical role of improved combat care and rapid evacuation from the battlefield to provide high performance emergency medicine. The latter using VTOL aircraft is only possible in a combat environment where the United States and its allies have near air supremacy.

[22] See Paul K. Davis and Peter A. Wilson, *Looming Discontinuities in US Military Strategy and Defense Planning – Colliding RMA's Necessitate a New Strategy*, RAND, OP326, 2011 for a discussion about the hypothesis that there have been four revolutions in military affairs (RMAs) as ways of war in the twentieth century and have interacted in a large-scale form of measure and countermeasure during past and future conflicts. RMA I is the way of war fought with combat vehicles and industrial production of which current small arms technology is a part. RMA II is the way of war of the insurgent of what can be called Maoist revolutionary warfare. RMA III is the way of war if not non-war with the use or threat of nuclear weapons and their long-range means of delivery. RMA IV is the way of war fought through the use of silicon and all of the manifestations of the digital age including precision guided munitions, sensors, cyberspace, and robotics.

simply rivals to the paper cartridges until their universal adoption in the late 19th century. Even revolutionary changes like automatic fire were quickly universally adopted by industrialized armies following their experiences against them during the First World War.

Adoption is not the only path within history though; modern armies require industrial bases to both create and support their weapons systems and their opponents often cannot match those production bases. While this doesn't always prevent the adoption of the weapons systems, even when they can be adopted they cannot be replicated or used to their full potential.[23] Instead, the far more sustainable path has been the search to nullify them. Strategic and tactical innovations are historically the most prevalent of countermeasures, with the battlefield firepower of modern armies often instead forced into suboptimal engagements. Classic guerrilla warfare, from Spain the Napoleonic War to the current insurgencies in Iraq and Afghanistan are pursued specifically to deny the overmatch potential of their opponents.[24] This often is augmented by the insurgents' own technological innovations that are often impromptu adaptations of materials that are locally manufactured or commonly available.[25]

Insights into the Strategic and Tactical Environment of 2022-2042

Key Insights

- The definition of "technological overmatch" will change dramatically over the next 30 years
- It is impossible to discuss technological overmatch without considering rules of engagement

The definition of "technological overmatch" will change dramatically over the next 30 years

The demand signal for small arms has become dramatically more complex during the past eleven years. Prior to the September 11th terrorist attacks and the beginning of Operation Enduring Freedom, the role of small arms had been cast by the traditional purpose of the infantry in the major ground wars of the 20th century, which was to close with and destroy the enemy with an acceptance of heavy infantry casualties. The principal challenge for small arms design was how to deliver the maximum ballistic effect reliably and with sufficient accuracy and a high enough rate of fire to suppress and/or kill opposing forces. In this paradigm, overmatch is defined by the physics of delivering kinetic effects. The yardstick for measuring overmatch is the enemy's own small arms. In other words, a small arm system provides overmatch if it enables the Soldier to put more rounds further down range with greater accuracy than those possessed by the enemy.

[23] A pertinent example would be the West African empire of Samori Toure. Samori had imported a large number of Western breech-loading and magazine rifles before the French invaded, but without the mechanized base to support the logistical requirements, he was forced to rely on outside trade to maintain them. This eventually failed, leading to his defeat.

[24] Other pertinent examples are the IRA's adoption of guerrilla tactics following the Easter Rising (1916-1923), the 'Bitter Enders' of the Second Boer War (1900-1901), the Zulu of the Bambatha Revolt (1906), the Communists in the Chinese Civil War and 2nd World War (1934-1949), the Viet Minh of the Indochina/Vietnamese Wars (1946-1975)

[25] These are often low-tech, such as the adaptations of tiger traps in the Indochina conflicts. However, recent conflicts, such as Iraq and Afghanistan, have seen the adaptation of civilian information technology, such as cell phone triggers for Improvised Explosive Devices (IED).

A new paradigm appears to be emerging. This is the requirement that infantry-type and SOF-type units are able to conduct tactical maneuvers over a highly dispersed fashion while being able to use a family of weapons that provide a full spectrum of lethal and non-lethal effects. At the present time US ground combat units with contemporary small arms have a measure of overmatch against all non-nation state opponents. This is derived from the near unilateral deployment of Soldiers equipped with body armor, night vision and range finding technology, superior tactical communications, and rapid access to supporting arms above the squad and platoon echelon. Furthermore, US combat troops now are trained to a higher level of personal and tactical competence with the extensive use of near real-life simulators. These advantages will fade if "irregular forces" acquire similar capabilities.[26] Certainly high technology enabled nation state opponents will be able to replicate these enablers if they so desire.[27] Furthermore, our recent re-acquaintance with counter-insurgency provides a reminder that even a technologically inferior enemy can mitigate our edge in "gadgetry" through guerilla-style tactics and effective use of propaganda. Therefore, overmatch in the middle part of the 21st century will no longer be defined strictly in terms of the traditional variables of caliber, maximum effective range, and rate of fire.

However, it became clear during this study that the institutional Army's definitions of the measures of effectiveness that comprise overmatch are becoming outdated. Despite investments in non-lethal and scalable technologies, Army doctrine, training, and acquisition structures for small arms still fundamentally embrace the model of small arms as a delivery vehicle for lethal, kinetic effects delivered against point targets by an individual marksman. Many of the Soldiers we interviewed expressed frustration at the limited range of options available to commanders for shaping effects at the squad and platoon level without calling on assets that are not organic at those echelons (e.g., close air support and indirect fire, which require too long to get effects on target and are often restricted by rules of engagement). It is beyond the scope of this study to prescribe a new definition for 21st century small arms overmatch. However, it will likely involve the ability for squads to tailor effects in real time to achieve decisive action regardless of the tactical situation. We recommend that the Army G3 lead a deep consideration of how the Army should define, and more importantly, measure overmatch in the future. The development of new measures of effectiveness/measures of performance for overmatch in small arms is essential to guide research and development of new small arms systems.

The institutional Army's definitions of the measures of effectiveness that comprise overmatch are becoming outdated.

[26] One response to this overmatch on the battlefield, opponents in Iraq and Afghan extensively resorted to improvised explosive devices (IEDs) that inflicted significant casualties during the later course of both conflicts, The US response to this emerging threat was the creation of Joint Improvised Explosive Device Defeat Organization (JIEDDO) which has sent billions of dollars on countermeasures with mixed results. Further, over $20 billion was spent on the crash effort to deploy thousands of Mine Resistant Ambush Protected (MRAP) armored vehicles where light infantry especially in Iraq began to operate as motorized armored infantry. Finally, there was the major innovation by the Army in the creations of Task Force Observe, Detect, Identify, and Neutralize (ODIN) to provide US forces with a powerful anti-insurgent reconnaissance strike complex.

[27] Recent analysis of combat casualties in OIF/OEF that body armor has dramatically reduced fatal gunshot wounds from about 33% during prior wars to about 4.6%. On other hand, explosive mechanisms of injury with the IED as the most common account for over 75% of all combat casualties. Also, the use of MRAP armored personal carriers proved very effective in reducing IED casualties. See Belmont, op.cit., With the exception of Iran supplying lethal self-forging IED warheads, the battlefield threat was limited with the insurgents gaining little or no access to contemporary PGMs such as MANPADS and ATGMS much less precision guided indirect fire weapons.

It is impossible to discuss technological overmatch without considering rules of engagement

Despite an unprecedented appetite for violent forms of entertainment, the American people have relatively low tolerance for the carnage of actual warfare.[28] The same is true amongst our allies. Coupled with the rise in unfiltered battlefield reporting[29] there will be ongoing pressure to reduce the "mess" associated with the close fight. A search for "Afghanistan firefight" on YouTube yields over 17,000 videos – it is unlikely that many were submitted for OPSEC approval. As noted above, the Army's current family of small arms severely restricts Soldiers to a limited set of effects options that kill and maim indiscriminately. It is a testament to the character and training of the American Soldier that so few noncombatants are killed given the overwhelming lethality of today's small arms. However, it is clear that the trends toward limited engagements with highly restrictive rules of engagement (ROE) to limit collateral damage will continue to stress today's small arms capabilities. It is unclear whether the Army S&T community has adequately appreciated this emerging dynamic and considered the implications for its R&D investments.

A search for "Afghanistan firefight" on YouTube yields over 17,000 videos – it is unlikely that many were submitted for OPSEC approval.

How might the Army as a whole, and the S&T community in particular, deal with this new paradigm? One option is to continue optimizing our small arms for the kinetic fight and mitigate collateral effects through tactics and rules of engagement. This is certainly the path of least resistance from a materiel standpoint and requires little to no disruption of our current processes for acquiring small arms technology. S&T investments could go to enhancements to ammunition, fire control, and enablers (e.g., optics and night vision) to incrementally enhance the precision and reliability of traditional firearms and their users.[30] Technologies such as the XM25 can be developed to expand options for delivering lethal effects.[31] However, this approach places the entire onus on Soldiers to make one category of tool work for every job. As we have seen in Iraq and Afghanistan, ROE makes for a poor rheostat in controlling the application of non-selectively lethal effects in the ebb and flow of combat.[32]

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[28] This is a core argument of Steven Pinker, op.cit., that modern high technology industrial nations have a lower tolerance for domestic violence. See Evan Wright, *Generation Kill*, Penguin Group (USA) Inc., 2005, for the suggestion that some troopers emerged as "natural born" killers. For a comprehensive overview of the near and long term psychological and physiological consequences of close combat/police acts of killing see Dave Grossman and Loren Christensen, On Combat: The Psychology and Physiology of Deadly Conflict in War and in Peace, PPCT Research Publications, 2004.

[29] Over the past several years there has been a rising tide of "amateur" combat reporting including propaganda video shot by insurgents and videos shot by US Soldiers and directly uploaded to sites like YouTube. It has proven next to impossible for leadership to control the flow of combat video from the field, and equally impossible to manage the strategic communications implications of this trend. The proliferation of small, internet-connected video recorders, coupled with the rise of the "always connected" generation of Soldiers, will only exacerbate this trend.

[30] For example, the effectiveness of the 5.56mm ammunition may dramatically decline if US ground forces face opponents well equipped with advanced body armor.

[31] If deployed on a significant scale, the XM25 Counter Defilade Target Engagement (CDTE) System may be provided with a wide range of ammunition natures other than fragmenting and dual-purpose HE. Other munitions could include an array of less than lethal options such as tear-gas, nausea gas, and optical-sonic dazzlers.

[32] To take into account the longer engagement ranges in rural Afghanistan than those found in more urban Iraq, US ground forces introduced the M14 Enhanced Battle Rifle (EBR) as a longer-range semi-automatic sharp-shooting rifle, the Knight M110 semi-automatic sniper rifle as well as the Barrett family (M82 → M107A1) of 12.7x99mm anti-material/personnel weapons. Also, the Marines have decided to buy the Mk48 light machine gun/automatic

The obvious solution is to invest in developing technologies that allow for some degree of scalability along the lethal-nonlethal dimension. The Army is currently funding several non-lethal and scalable effects science and technology programs. However, it is not apparent that there is a comprehensive or cohesive systems approach to developing future generations of small arms technologies that is designed to provide the full suite of capabilities that Soldiers and squads will need in future conflicts. We recommend that ASA(ALT) portfolio leads work with TRADOC, Army G3, USMC, and SOCOM to develop an architecture for small arms to baseline current investments and guide future S&T activities.

Insights into Future Technologies for Small Arms

Key Insights

- Future small arms technologies will blur established "lanes" within the S&T and PEO/PM community
- Emerging technologies promise to radically change the nature of how we define the relationship between Soldiers and small arms
- Few of the concepts provided overmatch across all alternate futures

Future small arms technologies will blur established "lanes" within the S&T and PEO/PM community

The ideation exercise generated several new concepts for small arms technology for 2022-2042 (detailed in Appendix D). Many of these concepts, such as the "Combat Lightweight Automatic Weapon System" and the various scalable and non-lethal ammunition ideas, mirror existing S&T efforts. Others, such as the "IQ Box" that provides each Soldier with a personal digital assistant, much like Apple's Siri system, are novel in the small arms arena. A common theme running through most of the concepts that were generated is that the definition of "enablers" for small arms will expand over the coming decades. In particular, future small arms will rely heavily on computational power and associated supplies of power and energy well in excess of current small arms electronics. Networked small arms were also a recurring theme emerging from the ideation exercise, with most participants agreeing that future weapons will be heavily enabled via links to the battlefield network, with all the associated risks of the networked force. "Smart arms" were another recurrent theme, with artificial intelligence built directly into the small arms platform.[33]

It is worth noting that very few of these concepts fit into the traditional commodity bins by which we develop and acquire small arms technology. Who "owns" the development of a "smart round" that is connected via the tactical network to a fire control robot controlled remotely by a squad leader from three blocks away? What PEO or PM is

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rifle with 7.62mm ammunition as a replacement for the Vietnam derived M249 SAW with 5.56mm ammunition. In the near-future squads and platoons may be trained with an "arms room" of weapons to allow for different weapon mixes deployed during very different battlefield environments. The MOS for the "standard rifleman" may disappear over time.

[33] Networked weapons much less electronic enabled small arms will have to be designed to be very resilient in the face of a wide spectrum of cyber, electronic and directed energy warfare weapons. Ideally they will be still able to function in a "dumb" mode in these electronically "dirtied" battlefields. For example, will an XM25-type weapon need to be able to function if it and its munitions are subjected to a tactical electromagnetic attack delivered by rocket artillery or heavy mortars?

responsible for procuring and fielding such a system? The concepts generated by this study strongly suggest that the Army will need to rethink its task organization for small arms research, development, acquisition, and fielding. Furthermore, as budgets tighten and missions converge it makes sense to review how the Army might better coordinate its small arms S&T activities with the other services, particularly the Marines and SOF community. Any effort to reform the current system will certainly meet with significant resistance from current stovepipes and outside interests. However, the future demands of small arms development will almost certainly require a different organizational model.

> *Who "owns" the development of a "smart round" that is connected via the tactical network to a fire control robot controlled remotely by a squad leader from three blocks away? What PEO or PM is responsible for procuring and fielding such a system?*

Emerging technologies promise to radically change the nature of how we define the relationship between Soldiers and small arms

The most salient finding from the ideation exercise is that experts from across the tactical and technical community agree that the next 30 years will be defined by the emergence of technologies that will fundamentally change the way small arms are defined. Many of the concepts foresaw technologies that create direct interfaces between the Soldier and his small arms system, through direct brain interfaces, for example. Other concepts envisioned Soldiers equipped with exoskeletons that could carry significantly more effects options while vastly improving the accuracy of small arms fire by providing enhanced targeting information through heads-up displays. (Of course, the concept of the "Starship Trooper" is hardly new, but the participants in the ideation exercise were convinced that this technology will pass from science fiction to reality given trends in high-density power sources and optimized control systems.) Many of the concepts proposed offloading small arms onto robotic platforms of various types. Again, this is not a new idea. What emerged from the exercise, however, is that these concepts are not only viable, but would provide squads with truly disruptive capabilities to employ flexible effects options at the squad level – as noted above, this is the "holy grail" of small arms for the 21st century. Taken together, the concepts generated during the ideation exercise pose several questions for Army leadership to consider.

Will the traditional assault rifle become obsolescent?

Many of the concepts generated at the ideation exercise, such as the "Kinetic Modular Weapons Platform" and "Genius Ammunition Project", envisioned the replacement of the assault rifle firing high velocity small caliber kinetic ammunition with systems based around electronically-controlled high explosive (HE) and directed energy projectors. This trend is seen in the successful fielding of the XM25, and will accelerate if the current XM25 is proven to more than just an upgrade to the M203/M320 grenade launcher.[34] Further, there is the prospect of the wide spread diffusion of current and next generation body armor to non-state and state combatants thereby

[34] As a less technologically demanding upgrade of the single shot grenade launcher, the Marines decided to acquire the Milkor Mk32 40mm multiple grenade launcher (MGL), a six-shot revolver weapon with a range similar to the original single-shot M79.

requiring more lethal munitions that include HE and larger caliber kinetic weapons.[35] 12.7mm guided bullets may emerge by the end of this decade thereby increasing one-shot lethality at ever greater distances.[36]

Will we see the emergence of the armored exoskeleton as the platform for "dismounted" operations?

There was extensive discussion at the ideation exercise of the potential for exoskeletons to eliminate the long-standing problems of Soldier load while providing a greater range of effects options at the squad level. The exoskeleton-enabled "Starship Trooper" has been a gleam in the eye of science fiction writers and some in Army S&T community since the late fifties and the target of recent investment by DARPA and the services. The two fundamental technical barriers to practical exoskeletons for infantry forces have been developing safe and reliable control systems and providing the huge amounts of power that an exoskeleton would need for sustained operations. The control system problems are more or less solved, and have benefited greatly from investments in bipedal robotics. The power problem remains vexing, but investments in S&T promise breakthroughs over the next few years. For instance, nano-weave technology would significantly reduce the weight of an exoskeleton without compromising its ability to augment human strength. A lighter suit requires less power, which could be provided by fuel cells that are currently in development. Aside from many survivability attributes, the combat suit could feature "mounting points" for several different types of small arm providing Soldiers a range of effects options. Feedback-control between the suit and firing systems could also eliminate much of the human error in marksmanship associated with stabilizing the body. Interest and investment in the exoskeleton concept has waxed and waned. Exoskeletons are truly at the cutting edge of several scientific and technical domains – if the Army sees value in this concept for the middle part of the 21st century, investment in enabling S&T must begin now. We recommend that ASA(ALT) work with DARPA and the S&T Enterprise to determine the state of the art in exoskeleton-related technologies and whether a TECD or ATO-level program should be funded to develop these systems. Furthermore, we recommend that ASA(ALT) lead an ongoing dialog between TRADOC and the S&T community to ensure that the revolutionary capabilities of an exoskeleton are matched with appropriate developments in doctrine and materiel requirements. The exoskeleton represents a revolutionary or radical innovation, and could be disruptive[37] – there is every reason to expect that Soldiers would need different doctrine to employ this capability effectively.

Exoskeletons are truly at the cutting edge of several scientific and technical domains – if the Army sees value in this concept for the middle part of the 21st century, investment in enabling S&T must begin now.

[35] For an overview of the history and future of the assault rifle and the effort to find an optimal ammunition see Anthony G. Williams, "Assault Rifles and Their Ammunition: History & Prospects", November 2012, http://www.quarry.nildram.co.uk/Assault.htm

[36] David Crane, "Sandia Lab Self-Guided Bullet: Laser-Guided .50-Caliber Saboted Coming for the US Ordance M2HB-QCB (Quick Change Barrel) "Ma Deuce" Heavy Machine Gun? Meet the Possible Precision .50-Cal Projectile of the Future", *Defense Review*, February 6, 2012.

[37] Terms like "evolutionary", "revolutionary", "leap-ahead", and so on are often used loosely in the Army S&T community. A more concrete and widely-used framework was articulated by Clayton Christensen in *The Innovator's Dilemma"*. Christensen distinguished between "sustaining innovations", which might be incremental or radical, and "disruptive innovations". Sustaining innovations extend the capabilities of an existing product category, such as the assault rifle. In industry, sustaining innovations are targeted toward existing markets – the analogy in the defense world is that a sustaining innovation supports existing doctrine, organization, and leadership principles. A disruptive innovation creates entirely new markets and, over time, displaces existing technologies (hence the disruption). A distinguishing feature of a disruptive technology is that it is often initially viewed by existing market leaders and customers as less capable that existing products, though it offers unique features that appeal to a niche market. In the defense world, a disruptive innovation as it matures, creates an entirely new capability set that requires change in doctrine, and potentially organization.

Will ground robots follow the disruptive path of unmanned aerial systems?

Perhaps the most salient theme that emerged during the ideation exercise is the disruptive potential of unmanned ground robotics at the squad level. Of course, Packbots and other small unmanned vehicles have become common for modern squad and platoon operations. Current S&T programs are developing robotic "mules" that will reduce Soldier load. However, the implications of squad-level robotics extend far beyond reconnaissance and load carriage. For example, recent technologies like the SWORDS robot demonstrate that a squad robot will likely evolve into a fighting system equipped with what used to be considered crew served weapons. This will allow 12.7mm-class machine guns, high capacity grenade/mortar launchers, and next generation small ATGMs to migrate down to the squad level. To reduce the requirement of the trooper to directly control these fighting systems, there will be a big push to develop semi-autonomous robots requiring low bandwidth communications. By the late 2030s the ground robot fighting system may take on complete autonomy. Although beyond the scope of this analysis, this technological threshold is fraught with major legal, strategic, and moral issues.

To continue this line of thought, several of the concepts from the exercise envisioned micro-UAVs flying above the squad. The larger of these will likely be armed with the weapons carried by the combat robots and are designed to provide persistent armed over-watch. The other class of UAVs will by flying micro machines that will be used primarily for battlefield reconnaissance and replace the current Raven class small UAV. Further these flying machines will have the capacity to swarm and set up multi-link communications networks. Their endurance will be enhanced by their capacity to draw energy from any functioning source of electricity such as power lines.[38]

As small unit robotics continues to develop it will make less and less sense for success at the tactical level of war to hinge on the ability of humans to accurately fire a rifle (or any other weapon of similar form factor). It is no secret that the human biomechanical system is profoundly sub-optimized for the mechanical task of firing a weapon to achieve precise effects. Postural sway, the optics of the human eye, and numerous other factors combine to limit the degree of accuracy that a human shooter can obtain. It is not apparent that there is a ready technological fix that can overcome millions of years of evolution. Shooting is fundamentally an algorithmic exercise – a precise shot is the solution to straightforward (if multivariate) geometric and physical equations. This is exactly the kind of mechanical task that robots do well. Freeing Soldiers from the mechanical task of shooting would enable them to focus on maintaining awareness of the tactical picture and making decisions. Offloading the physical mechanics of shooting to a robotic platform, with human control over the decision to shoot, would also free up time currently spent on marksmanship drills for Soldiers to train on making complex decisions during tactical engagements. Given the push to give greater responsibility to lower echelons of command this kind of training time will soon become an urgent need.

How will air assault and ground vehicles need to change to accommodate exoskeletons and/or robotically-enhanced squads?

Finally, as a cautionary note, the development of exoskeleton-equipped infantry or the provision of the infantry squad with increasing robotic assistance will dramatically increase the footprint of the squad and will affect the design of the next generation VTOL assault aircraft and armored infantry carriers. Either the next generation infantry assault vehicles will either have to be much larger with a larger payload thereby being more costly or that infantry squads and platoons will have to become even more specialized. One could imagine the emergence several classes of infantry that could include: a) light SOF; b) heavy assault infantry aka Starship Troopers; c) heavy infantry with robotic enablers; and c) mechanized infantry that fight from and near their parent fighting vehicle.

[38] The US will likely retain major advantages in unmanned vehicle technologies into the 2020s when the technologically advanced Asian powers such as China, Japan, and South Korea catch up. See Graham Warwick, "Cooling Down? Export and civil unmanned-aircraft demand will grow, but mainstay military markets may slow", *Aviation Week & Space Technology*, December 31, 2012 for a discussion of current UAV trends.

The mix of next generation small arms for each type of infantry unit may become highly specialized. The answers as to how to address these emerging trends will require analysis that takes a much more holistic view of future US Army small arms requirements. It is unclear whether the tactical and technical communities of the Army have deeply absorbed the full implications of armed squad robots across the DOTMLPF spectrum. We recommend that ASA(ALT), TRADOC, and the intelligence community collaborate on a "deep dive" into this issue to roadmap the technologies that are feasible and prepare for the doctrinal, organizational, and acquisitions changes that will be driven by squad robotics.

It is unclear whether the tactical and technical communities of the Army have deeply absorbed the full implications of armed squad robots across the DOTMLPF spectrum.

Few of the concepts provided overmatch across all alternate futures

Very few of the small arms related concepts generated during this exercise fared well across all of the alternate futures that were presented to the participants – details of the analysis are provided in Appendix D. Most did quite well in scenarios that stressed traditional force-on-force action but less well in situations that required more nuanced application of lethal and non-lethal effects, especially in situations requiring crowd control. Again, it is important to stress that the alternate futures generated for this study are not meant to be exact predictions of any particular set of future events. Instead, they exemplify strategic and tactical themes that will characterize future operations to one degree or another. For instance, it may not be the case that active duty Army units are deployed to control domestic civil unrest, as in the Turning Inward scenario described in Appendix B. However, it is plausible that those forces will be called upon to control civil unrest somewhere in the world, and that they will be bound by ROE to treat the populace for all intents and purposes as if they were American citizens.

The requirement that US small units should have a clear overmatch against irregular opponents appears compelling. On the other hand, the small arms ecosystem may be strongly squeezed as the US ground forces attempt to modernize at the echelons above squad and platoon in the face of sustained budgetary austerity – exacerbated by a prolonged period of budget priority given to the USN and USAF. An investment strategy for the next generation of small arms should be closely integrated with the larger investment in the individual Soldier system as well as in those enablers that will operate at the squad and platoon echelon. We recommend that ASA(ALT) continue to engage with TRADOC and other thought leaders in future operations to articulate the demand signals that will drive future small arms needs and that the S&T portfolio be reviewed regularly against these projections to ensure that the strategy for small arms technology development remains adaptive to future trends.

An investment strategy for the next generation of small arms should be closely integrated with the larger investment in the individual Soldier system as well as in those enablers that will operate at the squad and platoon echelon.

Insights into the Nature of Innovation in Army S&T

Insights

- The Army has a rich tradition of small arms innovation, including many concepts that arrived "before their time". These represent a significant, largely untapped resource.
- Innovation is an inherently human exercise dependent on "hot teams" given time and space to think big.
- Ideation must become a routine business practice for Army S&T

The Army has a rich tradition of small arms innovation, including many concepts that arrived "before their time". These represent a significant, largely untapped resource

Early on in the process of doing background research for this study it became clear that there is a remarkable historical record of innovative thinking about small arms technology concepts that goes largely untapped by our current science and technology community. One example of this is a concept for a "folded" 5.56 cartridge described in a 1976 technical report available for download from DTIC (Donnard, Rhodes, & Hennessy, 1976). The concept, which was created by Andrew Grandy at the Frankford Arsenal, was a radical reconceptualization of ammunition design. Instead of the traditional axial cartridge the folded ammunition concept located the propellant charge alongside the bullet. While unconventional, this allowed for a reduction in the packing volume and weight of each cartridge. Analysis presented in the report demonstrated that adoption of the concept would reduce Soldier load by three pounds while reducing bolt acceleration and extending the life of weapon parts.[39]

It is unclear what happened with the folded ammunition concept or why it was not pursued. However, the point to be made is that the Army (and other services) has a history of innovative concepts that have largely been forgotten as institutional memories have faded. The fact that many of these ideas have been documented in technical reports means that there is a remarkable resource of concepts that could be mined to inform current thinking. During the present study the study team became acquainted with the Federal Research Division (FRD) of the Library of Congress. This office provides federal agencies with directed research services utilizing the resources of the world's largest library. The FRD can search for and analyze reports and other written materials across a wide variety of databases, including domestic (e.g., DTIC) and international sources. To the best of our knowledge, the Army science and technology community makes little use of this service. We recommend that ASA(ALT) and the S&T Enterprise leadership investigate how the capabilities of the FRD could be leveraged to enhance the Army's corporate knowledge of innovative small arms concepts from the past that could be worth revisiting today.

Innovation is an inherently human exercise dependent on "hot teams" given time and space to think big.

Innovation does not simply happen – it is the result of a delicate alchemy that emerges from the right group of people given the tools they need to create in an environment that promotes free-ranging thought. Volumes have been written on the psychology of innovation and creativity, and decades of research in individual and organization behavior underscore the conclusion that innovation must be nurtured by an organization and tended

[39] The idea of the "folded" cartridge became the case-less ammunition concept and was touted as the "next big thing" in small arms ammunition. Although the US Army made, by small arms standards, a major R&D investment in same, the actual results have been disappointing. The issue at hand is the reliability and integrity of the rounds of ammunitions when deployed in a high stress military operational environment. At the present time, France and the UK have continued to make an investment in a folded 40mm Case Telescoped Ammunition (CTA) for an automatic cannon as the primary weapon for the next generation infantry fighting and scouting AFVs.

carefully to avoid several common pitfalls. For instance, it is not enough to indiscriminately select a group of people – no matter how expert they may be – and expect them to collaborate productively to create ideas that are new and useful. Innovation activities must be curated with an eye toward designing teams that bring multiple points of view on a problem and that can follow the basic "rules" of ideation, including:

- Deferring judgment. One negative element can destroy a successful innovation effort. The ability be critical of ideas is an essential part of generating useful ideas, but a group must have the discipline to defer criticism until many ideas have been "put on the table". The one exception to this is judgment of group process. "Hot groups" have a shared awareness of their work and are willing to challenge themselves to challenge assumptions and break out of "pet" ideas.
- Encouraging each other to share wild ideas, however unlikely or improbable on the surface. Wild ideas often contain the seeds of truly innovative (new, useful, and feasible) concepts.
- Build on the ideas of others.
- Stay focused on the topic. Groups have a tendency to get sidetracked easily and begin dissecting ideas too early, which reduces the number of fresh ideas that get generated and leads to premature criticism. Effective groups know this and exercise internal control to stay on task.
- Maintain respect on trust. Sharing concepts means exposing one's ideas to others, which can be uncomfortable for many. Groups that cannot maintain a positive dynamic will become guarded abd conservative, two traits that are deadly for innovation.

How should an organization go about recruiting hot groups for innovation activities? One approach, which was used in the current study, is to analyze potential group members using the tools of network science. Throughout the study process detailed in the report we worked with dozens of subject matter experts, each of whom completed a survey that we designed to elicit basic information that could be used to understand how experts in the small arms community are connected through organizational or other ties. This information helped us build balanced groups for the ideation exercise. The initial network analysis of the small arms study is detailed in Appendix E). It is extremely important to note that it is based solely on the data collected on the participants in this particular series of small arms futures activities. In order to be effective for decision-making, the data set has to be expanded to capture a much larger portion of the Department of Defense Science and Technology community. Based on the positive results of the proof of concept study, the Network Science Center at West Point plans to expand the effort in several ways. First, the team is establishing a community of innovators, inviting select experts from both inside and outside of the Department of Defense, called the Future of Army Science and Technology Network (FASTNet). Anyone can join the group and the hub of the group's activity is a web site that is currently under development. This web site will be a place for anyone interested in military research efforts to "gather" and discuss innovations in science and technology. In order to join the group, the candidate must complete an application, which includes similar data to that collected in the Small Arms Futures project and then be approved by the group moderator. As the group expands, an innovative ranking system will be implemented allowing members to gain stature in the group and assist in the weighting of linkages in our ever-evolving network model. Second, the team will continue to conduct analysis on the data set allowing us to devise new and innovative grouping algorithms, and techniques for identifying pockets of influence, both positive and negative, and identifying hidden influencers in the network.

As a "test" of how innovative our groups of domain experts were we also conducted a follow-on ideation exercise with a small selected contingent of cadets from the United States Military Academy. The hypothesis was that cadets, by virtue of their inexperience with the professional realm of small arms production, would produce less constrained concepts that could rival the "professionals" ideas on innovation. Happily, this was not the case. The cadets produced extremely similar results concepts, including utility robots, controlled drones, exoskeletons, and scalable effects. For comparison, the cadet concepts are presented in Appendix D.

Ideation must become a routine business practice for Army S&T

Another point to be made is that structured innovation is a skill that an organization must practice routinely. It is not enough to do occasional "brainstorms" or workshops with little forethought into how the results of the exercise will carry forward. Organizations such as 3M, IDEO, and others that excel in innovation make ideation exercises similar to the one done for this study a routine business practice. The experts that participated in the small arms ideation exercise were unanimous in their view that the Army often does this kind of activity as a "one off" in a "fire and forget" mode. A group of experts is gathered and produce new ideas that are generally documented in a report that almost nobody reads and that is promptly put on a shelf to collect dust. Often the same topic is revisited later with the same lack of planning for the follow-through. It is impossible to maintain forward momentum and energy under the "one off" model. Instead, the Army needs to make ideation activities a regular part of the S&T planning process, establishing a battle rhythm for technology innovation and ideation exercises similar to the Campaign of Learning used by TRADOC to refresh thinking about doctrine. In addition to increasing the number of innovative concepts that the S&T community generates, a regular ideation rhythm would create a mechanism for keeping the S&T community fresh by bringing in new and outside perspectives that can challenge conventional thinking and assumptions. We recommend that ASA(ALT) work with TRADOC and the S&T Enterprise to develop a regular process for conducting structured ideation activities that are grounded in threat and mission projections and that utilize sound analytical methods to encourage the transition from ideas "on the drawing board" to new S&T programs. This process would be particularly effective if aligned to TRADOC's annual Unified Quest wargame cycle.

It is not enough to do occasional "brainstorms" or workshops with little forethought into how the results of the exercise will carry forward.

Conclusions

This purpose of this study was to examine the “deep future” of small arms technology in the period 2022-2042. To that end a comprehensive approach was taken that included an analysis of lessons learned from the history of small arms, gathering of insights from experienced commanders, consideration of trends that will shape a range of potential future conditions for small arms, and development of innovative small arms technology concepts. This report has presented several key insights generated during this project. Our closing recommendation is that ASA(ALT) should keep the discussion going around these insights and consider whether some could be matured into new S&T activities. In particular, the experts involved in our ideation exercise were unanimous strongly recommending that futures-oriented ideation exercises such as this one should be a regular occurrence rather than a “one off”. During the post-exercise after action review all participants agreed that the Army should sponsor more forums for broad and fresh thinking about future technologies. The participants suggested making an exercise similar to the one described in this report a regularly occurring part of the S&T POM planning process. They expressed concern that doing activities like this in isolation as “one offs” failed to generate the critical mass of intellectual energy needed to drive innovative research and development over the long term. A regular “battle rhythm” of ideation activities would help build a culture of innovation and create the infrastructure needed to ensure that good ideas are captured and translated into revolutionary S&T programs. Therefore, we again recommend that ASA(ALT) consider making ideation exercises like this a part of the annual portfolio planning process, working with the S&T Enterprise and TRADOC to incorporate ideation as a regular business practice.

A regular "battle rhythm" of ideation activities would help build a culture of innovation and create the infrastructure needed to ensure that good ideas are captured and translated into revolutionary S&T programs.

We end by pointing out that the value in thinking about technology developments in the "deep future" often comes from insights into macro-level trends and strategic issues rather than the details of any particular concept. At the most fundamental level, this study points to a coming paradigm shift in small arms technology that will force the Army to radically revise its traditional notion of what constitutes small arms and how we go about developing and fielding such systems for the 21st century and beyond. There is something of a "perfect storm" on the horizon as China and other powers modernize and technological advances in robotics, network science, and other domains render obsolete many existing firearms technologies. It is unclear whether the Army S&T community is postured to adapt to this oncoming sea change. We recommend that ASA(ALT) lead a deep and comprehensive look at the 6.1 and 6.2 components of the small arms S&T portfolio and ask hard questions about whether our investments in future small arms technologies align with the forces that are shaping future operational needs. In leading this strategic conversation we encourage ASA(ALT) to engage individuals and organizations outside the traditional centers of mass involved with Army small arms science and technology. In thinking about the deep future it is essential to bring in perspectives well outside the box (and the beltway). This includes science fiction authors, historians, experts in social networks, and domain experts from industries unrelated to small arms development and manufacture. It is difficult to overstate the value of seeking these outside perspectives, particularly on an issue as central to the identity of the Army as the future of small arms technology.

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Appendix A: Historical Perspectives on Small Arms

The Parallel Evolution of Small Arms and Small Unit Doctrine

While the armaments of the Soldier are not the only determining factor in their deployment and tactical usage, it is undeniable that the two are closely bound together. Since the acceptance of firearms as a central weapon of infantry in the 17th century the technological advancements in small arms, be they evolutionary or revolutionary, have had a profound effect on the battlefield usage and maneuvering of these troops. The purpose of this section is to trace the role of small arms and their usage in the formation and evolution of small unit doctrine, specifically squads, platoons, and companies.

Small Units in the Muzzle Loading Era (1648-1866)

With the widespread adoption of firearms and their acceptance of the primary infantry arm following the military revolution of the 17th century, the stage was set for radical change in the way wars were fought. However, while the armies of Gustavus Adolphus[40] and his successors changed large unit tactics from dense blocs of pikemen and musketeers into more linear tactics, units like squads remained essentially unchanged from the pike era. At its heart, this unchanging idea reflected the tactical reality of linear warfare. While muskets were now widespread, the low rate of fire, often unreliable mechanisms[41], and inaccuracy of these firearms[42] meant that they needed to be used en masse for any appreciable effect against an opponent. This mass requirement meant that the basic unit that was left in consideration for tactical maneuvering was the battalion, as any smaller unit simply did not have the battlefield presence to be worth consideration.

This is not to say that units such as squads, platoons, and companies did not exist; however, these units were only accepted as disciplinary and administrative constructs. This form of the squad and platoon had existed since antiquity, with the subdivisions of centuries within the armies of the Roman Empire and continuing through the handfuls of professional troops available throughout the western world in the middle ages. With the advent of the Military Revolution these small units were again reformalized under non-commissioned and junior officers, but were still not viewed as separate maneuvering elements and the jobs of these officers was simply to make certain that their troops operated efficiently within the context of the larger military formation.[43] In turn, the officers would learn the basic skills of organizing men, taking care of the multitude of administrative tasks involved in a unit, and administering the disciplinary code of their army, a necessary stepping stone before moving on to command the larger maneuvering units.

It was this state of affairs that the nascent United States Army entered in to upon its formation during the American War of Independence. The early army, built upon European lines and drilled under the eye of von Steuben[44] and other European expatriates, consisted of the same maneuvering units that the European Military

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[40] Gustavus Adolphus (1594-1632) was the King of Sweden who is widely credited with spurring the period of rapid change known as the Military Revolution. His reforms included national service in the military as opposed to large numbers of mercenaries, the use of standardized uniforms, innovations in field artillery, changes in cavalry doctrine, the adoption of lighter small arms, and most importantly the adoption of linear tactics for better maneuvering and higher weight of fire.

[41] Matchlocks required a low burning match to remain lit with their firing pan exposed. Flintlocks required dry powder and a well maintained spring action. Either in the eras of their early adoption could be very unreliable under field conditions.

[42] Muskets were necessarily smoothbore and fired ball ammunition. As such, they had very limited range and terrible accuracy.

[43] Virgil Ney, "Organization and Equipment of the American Rifle Squad: From Valley Forge to ROAD," (CORG Memorandum, CORG-M-194, 1965), 5.

[44] Friedrich Wilhelm von Steuben (1730-1794) was a Prussian born military officer who served gained fame as the drill instructor for General George Washington's army during the American War of Independence. His training,

Revolution had bequeathed them. While the American forces made great use of light, skirmishing infantry with rifles,[45] their larger field successes in the War such as Trenton, Saratoga, and eventually Yorktown were field engagements along the accepted lines of European warfare. The tactical maneuvering and engagement remained the same as it was the most efficient method of using the military technology at hand. With the conclusion of the War of Independence, the American army was firmly ensconced within the doctrine of linear warfare as it existed and as such, at its earliest roots, small unit warfare remained a very limited idea.

This state of affairs within the United States military existed essentially unchanged through the 18th and first half of the nineteenth century. While small units still existed on occasion for smaller conflicts and skirmishing frontier warfare, the accepted mode of general warfare was still that of dense linear tactics. Command and control remained within shouting distance for non-commissioned and junior officers, volley fire provided the weight of fire necessary within close distances to be decisive, and the battalion remained the central unit of battlefield maneuver. However, with the advent of the Industrial Revolution, new technology was springing into being that would radically alter the small unit doctrine of not only the United States Army, but those of all of the European nations.

The initial technological changes to the small arms of the United States Army were evolutionary in nature, but portended the larger changes that the Industrial era would have on both the effect of weaponry and the alteration it would have on the practice of war. The early 19th century had seen an increasing number of rifled muskets on the battlefield with specialized units and by the 1840s the combination of rifling with the innovative bullet of Claude-Etienne Minie (known as the Minie Ball)[46] had created a system that drastically increased the effective range of firearms. This innovation, in combination with the increasing ability of militaries to machine parts, led to the widespread distribution of rifled muskets with Minie cartridges. While the initial uses of this system had little noticeable effect, it is worth noting that most of those conflicts were not widespread conflicts between two industrialized armies and thus their effects were not especially noticed at the time.[47]

The true technological crucible that would alter small unit tactics would be the American Civil War. With over a million rifles that were equipped with Minie Cartridges and percussion cap ignitions in use, the doctrines of the Napoleonic Era (which still contained a significant holdover from the earlier Frederickian linear era) would run headfirst into the new technological realities of war. The linear formations and tactics of assault led to monstrous casualties, causing for the first time a question of the doctrine that was in use. However, this would take time even as formation began to loosen up. The first hints of a more decentralized command began with the works of Upton's "New System" and Casey's "Tactics," both of which began to envision units such as the squad and platoon

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eventually formalized in his *Revolutionary War Drill Manual*, served as the standard practice of the United States Army until the War of 1812.

[45] The rifle, by benefit of the grooves in its barrel which spun the bullet in flight, offered extremely increased range and accuracy at the cost of rate of fire. It had already been adopted by several European nations for limited usage with specialized skirmishing troops, such as the Hapsburg's *Grenzers* and the various Germanic states' *Jaegers*. Early frontier warfare in the New World would further the doctrine of light infantry and raiding, with the French and Indian War strengthening the case for their use. That conflict saw the rise of French-Canadian *Coureurs des Bois* and the British colonists' units of Rangers, both of which were armed with rifles and were seen as premier wilderness skirmishers. The American Rifleman gained a strong mythological presence during the American War of Independence, one that endures to the present day.

[46] Claude-Etienne Minie was a French officer who designed a cylindrical bullet with a conical point and concave bottom which would mushroom into the rifling of a barrel upon firing. This sped up loading for rifles while also creating a much more accurate projectile at a longer range. The combination of rifling and Minie balls was known as the Minie System.

[47] Specifically the earliest uses of the system were in French colonial campaigns in Algeria, the Crimean War, and the Indian Mutiny of 1857, with none of these wars forcing large scale doctrinal changes- although the British and French would soon have to deal with the realities of Industrial War.

as actual tactical maneuvering formations.[48] However, the infantry tactics for the remainder of the war would remain heavily influenced by the earlier era even as the technological boom caused by the confluence of industrialization and war occurred around them.

Technological Boom and the Initial Alteration of Doctrine (1866 to 1914)

While doctrine would change little during the war, the technology of small arms would rapidly advance as the industrialized North took full advantage of its manufacturing and fabrication abilities. Breech-loading rifles, while not an entirely unknown quantity at the beginning of the war,[49] took on a new importance. The introduction of breech-loading quickened reloading times for the average infantryman, but in the days of paper cartridges would often be seen as still somewhat impractical.[50] However, these soon found synergy with metallic cartridges, themselves a product of industrial machining combined with the recent innovation of percussion caps. These new metallic cartridges combined bullet, propellant, and ignition system within a self-contained package, rapidly accelerating the reloading pace of the individual Soldier. Over the course of the Civil War the combination of breech-loading technology with metallic cartridges and often a magazine system of one sort or another transformed the individual small arm.[51] The weight of fire that could be laid down by a company now could match or exceed that of the battalion of an earlier era. While the industrial capacity of the Union could not produce enough to provide entire corps with these weapons, even the small units that could be equipped with them often proved decisive. Following the Civil War, the United States Army adopted breechloaders, although in a somewhat piecemeal fashion from 1866 to 1873. Over the next forty years the army would graduate from single shot black powder rifles to magazine-fed, bolt action smokeless rifles, but the alteration in doctrine began its alteration in trajectory with the effects of the Civil War and would continue throughout the period.

Industrialization and weaponry also began to cross-pollinate in another soon-to-be doctrinally significant way: automation. In 1862 the Gatling Gun was patented, and while not truly 'automatic' in that it required a user to crank it to force the firing action, it began the search for more effective automatic fire. The French Mitrailleuse followed in 1866, although it was more a mass volley gun. The final attainment of actual automatic fire was attained with the Maxim gun in 1884. Although again these were only adopted slowly by the United States Army, even the limited use of the Gatling multi-shot gun and the eventual effect of the Maxim machine gun on warfare (covered next section) would play its own role in altering the trajectory of small unit doctrine.

Simply put, the industrialization of warfare and small arms would force significant alterations in doctrine after the cessation of the Civil War. With the weight and accuracy of fire directed by a small unit only increasing with each passing year, the dense linear tactics of the pre-industrial era were suicidal. The next generation of officers, educated in the harsh school of the Civil War re-evaluated the American doctrinal system based on their experiences and the new weaponry context they found themselves in. Major General Emory Upton had already begun to alter his own practice, demanding that the eight man rifle squad be a central unit of maneuver under the command of a corporal. This in turn would be commanded and controlled as a platoon by a junior officer as a combined unit and then the company could act semi-independently.[52] It was from the adoption of Emery's

[48] Ney, 8. There will be more on Upton's "New System" following.
[49] For example, the Ferguson Rifle was a breechloading rifle created by Major Patrick Ferguson for use by the British in the American War of Independence. However, despite its effectiveness, it was not adopted for widespread use and Ferguson himself was killed at the Battle of King's Mountain in 1780.
[50] Although not entirely. The Prussian made Dreyse Needle-Gun was an effective breechloader with paper cartridges that would be used to excellent effect in the Wars of German Unification. However, the adoption of metallic cartridges was quickly accepted once it was practical to replace the Dreyse.
[51] Examples of this synergy include the Henry Rifle and Spencer Carbine, both of which saw significant usage within the Union Army.
[52] Ney, 15.

methods in 1866 that we can trace the usage of small units as the main unit of maneuver and combat in the United States Army.

This extension of independent maneuver to the smaller units was of paramount importance for the command and control within combat situations. While initially important for small column warfare against the plains Indians following the Civil War, it was the advent of combat against the Spanish and then Filipinos in the late 19th and early 20th century that set the tone for industrial warfare. Fighting in large formations against opponents with their own modern arms[53] necessitated a far more dispersed formation to avoid massive casualties. While the new firepower available meant that a dispersed formation did not lack for effect, it radically altered the command and control dynamics of the unit. Individual company members were no longer necessarily in earshot of their captain; companies themselves were spread out over five times the range they used to be, cutting the communication with battalion command. This meant that necessarily the actions of companies and platoons had to be autonomous from the previously monolithic battalion command and thus squads, platoons, and companies themselves became units of tactical maneuver. By 1914 the industrialized armies of the world had essentially adopted this as an article of faith through their own experiences,[54] but the tactics used within the small units remained informed by the wars they themselves had fought and by the firepower that could be maneuvered at this time.

The Great War and its Doctrinal Revolution

The advent of the Great War (1914-1918) would have a decisive effect on the role of small units and their doctrine, one forced on them by the technological context of the Western Front.[55] While the war began with as a conflict of massive maneuver by national armies, on the Western Front it quickly bogged down into an expansive trench war, stretching from Switzerland to the English Channel.[56] Contained within this front were the premier industrialized armies of their age--France, Britain, and Germany—but spread to such an expanse that command and control were simply unable to be exerted. The weight of fire able to be brought to bear by the recent adoption of machineguns made traditional methods of assault suicidal and there was little room for maneuver around strongpoints. With the breakdown of the abilities of high command to deal with local circumstances, command and control necessarily broke down to smaller units. The need to take and hold land in the trench context meant that increasingly platoons and squads needed to coordinate their movements on the micro level to gain the most advantage of their maneuverability and the most protection from supporting firepower. To aid in this, unit structures began to alter to support needed doctrinal changes. No longer was larger firepower such as machineguns or indirect bombardment capabilities coordinated at the larger unit level. Instead companies gained their own machinegun platoons to support their efforts and mortars were issued to smaller units to provide

[53] The Spanish had their own modern rifles and machineguns and the Filipinos had a great number of captured arms as well.

[54] British doctrine was mostly modernized as part of the Cardwell Reforms and its experiences in Colonial Wars. France experienced rapid alterations following its crushing defeat in the Franco-Prussian War. Unified Germany was informed by Prussian doctrine, which had unified the state through the Wars of German Unification- the Second Schleswig War, the Austro-Prussian War, and the Franco-Prussian War.

[55] Very few professional military thinkers and planners before the “Great War” foresaw the potential battlefield consequences of the late nineteenth century technological revolutions in small arms and rapid fire artillery using high performance fragmenting ammunition. A noteworthy exception to the rule was the writings of Ivan Stanislavovich Bloch (Blioch) who might well be viewed as the under-appreciated father of military operations research. See Ivan Stanislavovich Bloch and T. Steed, Is War Now Impossible? An Abridgement of The War of The Future In Its Technical, Economic, and Political Relations (1899), Kessinger Publications 2008.

[56] Other fronts (Eastern Front, Balkans, East Africa, Mesopotamia, etc.) retained their elements of maneuver, but since the current accepted doctrines worked within these contexts, they caused little change in the accepted mode of maneuver warfare.

localized 'artillery'. These efforts continued the push towards small unit autonomy, as now even the company was capable of internal 'combined arms' operations.[57]

However, even these initial changes could not break the deadlock involved in trench warfare. The breaking of trench lines required a combination of firepower, coordinated artillery support, and specialized training and doctrine within the small assaulting unit. In the later war these needs were supported by a combination of technological advancement and doctrinal focus. In terms of the technological advancement, the problem of trench assault came down to mobile firepower that could be used to match or overmatch that of defenders supported by machineguns. In pursuit of this goal, several important innovations followed. The first was the development of mass produced and reliable hand grenades, to allow for 'ordinance on demand.' The second was the development of light machineguns that could be carried with the assaulting squad.[58] Finally, late in the war the concept of automatic weapons that used pistol ammunition was explored, producing the first sub-machineguns.[59] These new weapons were used in conjunction with specialized units that had developed a combined arms assault doctrine that allowed for the isolation of a targeted section of trenches through combined arms fire, the safe approach of an assaulting squad, and then the capture of the section of trenches through the application of firepower.[60] Repeated successful applications of the new small unit doctrines convinced the Germans and their opponents of the necessity of small unit autonomy and firepower, although the final German offensive based on these ideas, Operation Michael, would fail and force Germany to request an armistice, effectively ending the war.

Interwar Years and whither the Americans?

The experiences of the Great War would radically alter the small unit doctrinal theories of the European powers. To these states, Germany in particular, the primacy of the small unit and its direction of firepower was now without question for military applications. There was now no longer a question of a separate machinegun platoon simply attached to a company to supply support; instead each squad must have an organic light machinegun to supply fire support to the squad as it would be expected to act independently. The interwar German doctrine even went further than this acceptance of light automatic weapons as a necessity; they instead structured the squad around the centrality of the machinegun and its fire support. Each of the members of the rifle squad was intended to defend and support the machinegun in its mission to deploy a heavy weight of fire downrange. In the next conflict, each German squad would have an exceptional light machinegun attached to it,[61] greatly increasingly the combat power of the small units.[62]

However, the American experience of the Great War had been different. Entering the war, the doctrine of the American Expeditionary Force (AEF) was predicated on the concept of the individual rifleman as the central component of maneuvering units and that the basic tactical doctrine was built around the concept of fire and maneuver.[63] As a result, the AEF was deficient in weaponry such as machineguns and had to borrow doctrine

[57] For example the French company consisted of four platoons, each of which now consisted of: 1 lieutenant, 2 sergeants, 4 corporals, 7 grenadiers, 6 rifle grenadiers, 6 auto-riflemen, and 17 riflemen. See Ney, 32.

[58] Examples include the Lewis Gun, the French-made Chauchat, and the early iteration of the Browning Automatic Rifle (BAR).

[59] The classic example is the German-made Bergmann MP18, which used *parabellum* 9mm ammunition

[60] These tactics were originally advocated by the French, but not put into effect. They were used extensively by the Russians in the Brusilov Offensive, but the imminent collapse of the Tsarist government cut their use short. The concept would later be formalized by the German high command with the adoption of Strumtruppen.

[61] Initially the high cost MG34, although this would later be replaced with the lower cost and legendary MG42.

[62] This was also supported by the German development of *Auftragstaktik*, the concept of localized control for leaders that allowed for extreme flexibility within the context of achieving tactical goals.

[63] The 1903 Springfield with .30-06 caliber ammunition was a derived copy (requiring royalty payments) of the 1898 Mauser 8x57mm rifle.

wholesale from the French and British armies upon their arrival.[64] However, despite their experience in the war and the alteration of doctrine that the AEF underwent in dealing with the realities of trench warfare, a central point of doctrine never changed: the supremacy of the American Rifleman. While the AEF would first supply themselves with machineguns and later borrowed Chauchat light machineguns while their own squad automatic weapons were developed, the American forces never accepted an organic machinegun into the squad, even as the squad became the central unit of tactical maneuver. Even the development of the Browning Automatic Rifle (BAR) did little to alter this practice- the BAR carried only ten rounds and was difficult to use in a fully automatic setting, thus it never overcame the reliance of American forces on the weight of rifle fire to provide the firepower base of the squad. At the close of the war, the AEF still accepted the platoon as they standard unit of maneuver as it allowed for limited fire support for rifle squads and specialist troops.[65] This doctrine carried through into the interwar years as the United States retained its structure of a separate machinegun platoon within a company that would in theory support the rifle formations on an ad hoc basis.

The Second World War and Beyond (1945-2012)

The Second World War saw the rise of what nowadays is termed combined arms operations. The German blitzkrieg was dependent on close cooperation of mechanized infantry, armor, and close support air units. To counter these tactics, the allies had to adjust their own doctrinal bases. However, despite the emphasis on the combination of arms, infantry doctrine still evolved as both a component of larger doctrine but also as an end unto itself. Late in the war, the Germans began to replace their Mauser rifles with the Schmeisser designed StG-44 Strumgewerhr (assault rifle) using the 7.92x33mm short round was the basis for the Kalashnikov AK47 that become the standard infantry weapon in the Warsaw Pact during the Cold War. This represented the major design and conceptual break from the bolt action and semi-automatic rifles equipped with full power rifle ammunition. During the Cold War, the Warsaw Pact reinforced their AK47 equipped squads with deployment of the PK light machine gun and the rocket propelled grenade (RPG), the latter a direct descendent of the German Panzerfaust RPG. This was the combination that gave the North Vietnamese firepower parity if not overmatch against US ground forces during the Vietnam War.

While squad and platoon echelon reforms were carried out by the French, Italians, and the British, the remainder of this piece will concentrate on the American experience.

The United States had, as noted, exited the First World War still reliant on a model the used the company as a command and control structure to supply supplemental firepower to the base unit of tactical maneuver, the rifle platoon. While the BAR was in theory a squad automatic weapon, in terms of a supporting fire role it was decidedly inferior to the British Bren Gun or the German MG34.

Instead the firepower of squads and rifle platoons would be provided by the recently adopted M1 Garand Rifle, a gas powered semiautomatic rifle that was carried by each rifleman. However, what this meant in practice was that the platoon was itself far more maneuverable than the company, since the individual rifleman could move much more freely than a dedicated support platoon such as a machinegun platoon or a mortar platoon. While this deficiency was not fatal to the US war effort, it was noted, especially as the war dragged on into its later stages. Following the war, the American military would finally have to grapple with the concept of squad oriented firepower and maneuver doctrine as the technology existed and experience against the German army indicated that the efficiency of squad level firepower and maneuver was extremely important in the current age.

To deal with the questions raised, in 1946 veteran infantry officers were called to Fort Benning to re-examine American platoon and squad level doctrine. The major question to be answered was the optimal structure of the

[64] James W. Rainey, "Ambivalent Warfare: Tactical Doctrine of the AEF in World War One," *Parameters, Journal of the US Army War College* Vol III, no3 (1983), 38.
[65] Stephen E. Hughes, "The Evolution of the US Army Infantry Squad: Where Do We Go From Here?" (Monograph, US Army CGSC, 1995), 5.

squad for its use as the basic tactical unit. The squad was restructured to a unit of eight men with an automatic rifle organic to each.[66] Subsequent experience in Korea brought this new formation into question and the demands for more firepower led to the division of the squad into two fire teams of four, each with a BAR. This would add weight of fire and continue to divide command and control for individual adjustments on the battlefield. A 1956 study, called A Study of the Infantry Rifle Squad (ASIRS) validated this idea of two separate teams with organic firepower, although the organization then became one squad leader, two team leaders, and four men per team (thus an 11 man squad). This was accepted even as in 1956 the United States announced the reorganization of the Army into what it referred to as the Pentomic Army for the nuclear age.[67]

This structure remained generally intact until a pair of dueling studies in 1961, the Optimum Composition of the Rifle Squad and Platoon (OCRSP) and the Rifle Squad and Platoon Evaluation Program (RSPEP)[68]. Both now dealt with the concepts of the squad and its place within the platoon. The introduction of the M14 Rifle[69] had provided increased firepower for the individual Soldier and the creation of the M60 Machinegun[70] now provided a real option for organic provision of firepower within the squad itself. OCRSP came to the conclusion that a singular larger squad with an organic M60 was the path forward. RSPEP looked to two smaller fire teams with an M60 squad attached at the platoon level. RSPEP was selected, continuing the Army's aversion to organic firepower within the squad, although the M79 40x41mm grenade launcher[71] was now issued within the squad itself.

The final configuration of the modern squad occurred following the Infantry Rifle Unit Study (IRUS) from 1966-1969. This study took into account the activities of the US Army in Vietnam and the recent adoption of the M16 Assault Rifle as the main small arm of the force.[72] It was finally with the IRUS that a Squad Automatic Weapon (initially the Stoner 63A but later the M249) was added to provide organic fire support to the squad. In addition, the needs to command and control were balanced with the optimal firepower to create what the military saw as fulfilling the purpose of the small unit. The most recent American innovation in the combat rifle was the emergence of the M4 carbine, a derivative of the M16. Initially, it was designed as a self-defense weapon for armored vehicle crews equipped with the World War II era 45 caliber M3 Grease Gun. Further, it was to equip infantry riding in the Bradley fighting vehicle who were expected to use same while carrying out mounted combat operations. That concept fell by the wayside, and the M4 carbine with improved optical sights and a longer barrel emerged as the standard combat rifle with the US Army during the Afghanistan and Iraq Wars. Of greater tactical consequence was the development of the Picatinny Rail that allowed the M4/M16 family of rifles to be enhanced with various night-vision optics, laser range-finder, flashlight, and the M203/M320 grenade launcher. These

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[66] Hughes, 7.

[67] Noteworthy was the rejection of an AK47-type assault rifle. The UK developed the EM1 Jason 6.25x43mm "bullpup" assault rifle in 1951 which fell out of favor after NATO standardized on the 7.62x51mm ammunition, and the British Army adopted the compatible FN FAL design. The bullpup design in the form of the SA-80 5.56x45mm assault rifle was adopted by the British Army in the late 1980s.

[68] Hughes, 11-14.

[69] The Springfield designed M14 with a larger magazine was an evolutionary development of the M1 and was the equivalent of the FN FAL design unlike the AK47. Because of its high power 7.62x51mm ammunition, the M14 with its butt-stock configuration proved to be uncontrollable in its automatic mode because of the problem of "skying".

[70] Interestingly, the M60 using the 7.62x51mm round was derived from the World War II era-MG42 designed for German paratroopers.

[71] Not to be confused with the Yugoslav designed M79 Osa (Wasp) 90mm recoilless anti-tank weapon.

[72] The USAF commissioned the development of the Stoner AR15 to arm its airbase security forces with a more effective light carbine than the M1 variant. Unlike the AK47 which used the 7.626x39mm short round, Stoner took advantage of the Remington developed high velocity 5.56x45mm round to provide for greater range and lethality than the Soviet weapon. The introduction of the M16 during the Vietnam War was fraught with protracted controversy especially when its reliability was called in question during combat, a result in part caused by a decision to change the propellant in the 5.56mm round and its gas operated design. Most of these operational problems were resolved by modifications made to the M16 by the early eighties.

innovations coupled with the Kevlar and ceramic materials revolution in body armor and helmets provided US ground combat forces "overmatch" against their opponents in both Iraq and Afghanistan.[73] To take into account the longer engagement ranges in rural Afghanistan than those found in more urban Iraq, US ground forces introduced the M14 Enhanced Battle Rifle (EBR) as a longer-range semi-automatic sharp-shooting rifle[74], the Knight M110 semi-automatic sniper rifle[75] as well as the Barrett family (M82 → M107A1) of 12.7x99mm anti-material/personnel weapons.[76] Not to be forgotten was the advantage provided US infantry forces by the Joint Forces' nearly complete command of the air. This allowed the free use of VTOL and fixed wing manned and unmanned aircraft to provide persistent ISR and responsive fire support.

Conclusion

The formation of military units has always been intended to balance the needs of effect, endurance, and control. Given these parameters, it is obvious that alterations to small arms technology would alter the conception and nature of the tactical unit of maneuver. At the outset and acceptance of firearms as a widespread weapon, dense linear tactics were accepted as a necessary precondition for effect. Smoothbore muskets needed a large number firing at a target to have a decisive effect. This meant that command and control could be centralized with large units, as they existed within a densely packed space. However, as arms technology increased and advances like rifling, metallic cartridges, and magazines increased the lethality of the battle space, it became both desirable and necessary to disperse units. Desirable in that now the weight of fire of a unit was such that a smaller unit could concentrate heretofore unheard of fire on a target and thus dispersal could widen the effect and necessary in that dispersal was necessary for a unit to endure combat. However, this then also dispersed command and control, meaning that command itself now devolved to local commanders, making companies and platoons, not battalions, the units of maneuver.

This process continued with the Great War, as machineguns, artillery, and trench warfare forced an evolution in doctrine and technology to deal with the constrained conditions. Local control became necessary as the conflict became too large for high command to control at the micro level. To beat the stalemate specialized squads with specific doctrines and technology were created, devolving command and control even more.

By the advent of the Second World War and beyond, the lethality of technology had led to the conclusion that squads could be and often were now the doctrinal unit of maneuver. From then on the question became one not of what unit should doctrine be based around, but how can be configure it and its technology to be most efficient at its job. This led to the adoption of fire team tactics, organic squad level automatic weapons, and finally the assault rifle and grenade launchers to provide full functionality to small units. Even in the modern day, the squad remains an individual unit of maneuver with self-contained fire support—a product of the evolution of the small arms that define the infantryman and his role on the battlefield.

In summation, the small arms technology realm, the creation and adoption of rifling, percussion caps, metallic cartridges, smokeless powder, breech loading, magazine rifles, and automatic fire are all part and parcel of the industrial revolution. Essentially, the modern assault rifle is a decedent from the late nineteenth century repeating rifle and machine gun, a product of the industrial age of warfare.

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[73] Additional stand-off firepower at the platoon echelon is provided by the heavy weapons squad equipped with a mix of M240 7.62x51mm general purpose machine guns and M96 Javelin fire-and-forget ATGM. The latter provides an anti-armor and bunker busting capability with a range of 2,500 meters.

[74] Current plans are to replace the M14 EBR as the squad sharp shooting rifle with a lighter variant of the Knight M110 7.62x51mm semi-automatic sniper rifle.

[75] To gain greater range the M24 7.62x51mm bolt action sniper rifle is being modernized and will use a .300 Winchester Magnum cartridge as the M24E1/M2010.

[76] The recently developed XM806 12.7x99mm lighter version of the M2 heavy machine gun optimized for light infantry use was cancelled in favor of an upgrade of the total inventory of the latter, the M2A1. This may be an example of a recent "small" arms innovation falling victim to larger Army budget pressures.

The current great change in military technology is the continued acceleration of the substitution of capital for labor to radically reduce the level of casualties that the United States might suffer during future military operations. Certainly, this trend will continue if future conflicts are viewed as those with limited objectives that do not require the expenditure of significant human casualties. The poster child of this phenomenon is the emergence of robotically enabled "targeted killings" to deal with non-state transnational threats such as al Qaeda and its affiliates. As for the prospect of future large-scale conflict with major regional if not near-peer powers, the challenge for the United States will be to gain much less sustain measures of military overmatch well above the echelon of the squad and platoon.

This of course leads us to the question of the next revolution in small arms technologies and their associated "Soldier systems". Given the past paradigms, it is pertinent to look towards the major innovations if not revolution in information technology, sensors, body armor, robotics and a new generation of small arms beyond the assault rifle to offer the radical changes that will lead to the next overmatch if only temporarily .

Appendix B: Alternate Futures for Small Arms

Development of Alternate Futures

One of the challenges in conceiving future technologies is that the value of a particular concept depends on how the security environment evolves. The kind of small arms that make sense in a future dominated by low-intensity, stability operations in urban environments could be quite different than the kind of small arms that would be needed to fight a large-scale ground war against a near-peer nation state. On the other hand, there could be concepts that make sense across a range of potential future scenarios. These are particularly promising from an investment standpoint as they afford flexibility in the face of an uncertain future.

No one can foretell the future with great accuracy, though we can make educated guesses about certain aspects of the future based on forecasting from demographic and technological trends.[77] The limitation of forecasting or foresight is that the "cone of uncertainty" around any projection grows the further into the future one looks. We can estimate economic growth for the US over the next 3-5 years based on projections from recent growth trends with reasonable confidence that our forecast will be "in the ballpark". However, what will growth be in 2040? We could make a projection based on recent trends, but so many unforeseeable factors could emerge over the next 25 or so years that our margin of error will be much greater than it would be for a nearer-term forecast.[78]

To get around this problem many forward-looking organizations develop a set of "alternate futures" that capture a range of possibilities for how the future might unfold. Within industry this approach is referred to as scenario planning, and is widely used by both industry and government agencies. An alternate future is a narrative describing one possible path the future might take based on a set of key drivers, or critical uncertainties. A set of futures can be developed around different scenarios for how the critical uncertainties resolve. For example, given that we are uncertain about the specific missions squads will perform in 2042, we could design a set of scenarios that captures a range of possibilities informed by data, doctrine, and strategic thought. The futures provide "sandboxes" for thinking about technology in a structured and rigorous way. Using alternate futures also helps ground ideation and mitigates risks common to generating technology concepts. For example, during group ideation settings it can often happen that participants advocate for "pet projects" – playing those ideas against a set of futures helps assess whether an idea stands on its merits. Another pitfall in ideation is that participants can get carried away with a "cool" technology that has exciting scientific and technical implications. Returning to a set of alternate futures helps ensure that these flights of fancy remain linked to capabilities Soldiers and squads might actually need.

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[77] The problem of forecasting the future appears nearly un-resolvable not unlike the challenge facing geologists forecasting the next earthquake or violent volcanic event. In the case of human history which can be best described as by the noted biologist Jay Gould as "punctuated equilibrium", the challenge is determining the timing and magnitude of next historic discontinuity. Several years before the fact, a UN report accurately described the fault lines and rising societal and economic pressures in the Middle East and North Africa (MENA). No one could forecast that a protest suicide in Tunisia would ignite the "Arab Spring". In a similar fashion, the shock of the strategic attack on the United States on 9/11 prompted a wide range of US responses including the invasions of Afghanistan and Iraq, the creation of the Department of Homeland Security and the emergence of the robotized enabled targeted killings that can be safely described as a historic discontinuity. Naturally, the proponents of mining "Big Data" with the next generation of petabyte if not exabyte computers hope for future mastery in this regard.

[78] A good example of a recent "surprise" in the global petroleum and natural gas industry is the rapid exploitation of the technological innovations in computational power, horizontal drilling, and hydraulic fracturing that has led to a revolution in supply in North America with the prospect of a similar global phenomenon.

This section presents a set of four alternate futures that were developed for the small arms ideation workshop described elsewhere in this report. Participants in the ideation workshop used these futures as tools to consider both technology concepts that were highly optimized for certain scenarios and concepts that would be useful across a range of futures. The scenarios provided a "gut check" that the concepts being discussed could be linked to real-world constraints. As with all scenario planning-style projects these futures were developed from extensive research and discussions with subject matter experts in trends that will shape the military, technology, and acquisition environment through 2042. Much of this expert insight was gained during workshops at West Point that focused on identifying assumptions that can be projected to remain valid well into the future, and axes of uncertainty, or variables that will profoundly impact the kind of small arms that the Army pursues. The assumptions and axes of uncertainty will be presented below, followed by four alternate futures. The futures were designed to span the range of potential outcomes that could emerge from the interactions among the assumptions and uncertainties. Readers interested in learning more about the methods used to develop these futures are encouraged to consult The Art of the Long View by Peter Schwartz (1996) and Scenario Planning by Kees van der Heijden (2011).

Assumptions about the Future

The future of small arms technology in 2022-2042 will be shaped by a rich web of interconnected and dynamic factors. While many sources of uncertainty will be in play, there are certain aspects of the ''small arms ecosystem'' that can be anticipated with a fairly high degree of confidence. These trends form a common foundation that will play out in all of the alternate futures explored below, though the implications will often depend critically on matters of a less predictable nature.

1. The defense acquisitions process will remain deliberate and lengthy.

Volumes have been written, quite literally, on the need for reform in the defense acquisitions process. The Joint Capability Integration and Development Systems, or JCIDS, was designed to mitigate risk to taxpayers in the development and procurement of military systems. On paper, the process is logical, if Byzantine. However, there are very few stakeholders who would argue that the system strikes an appropriate balance between proper stewardship of taxpayer dollars and the kind of agility and innovation our armed forces require.

Despite the obvious shortcomings of JCIDS, the experts that participated in our workshops and interviews universally agreed that there is little likelihood that a more responsive acquisition system lies anywhere on the horizon. While reform is likely, and may be very comprehensive, the consensus was that the process would remain risk-averse and lengthy well into the future.[79]

2. Weapons proliferation will continue to accelerate, providing future enemies with increasingly advanced capabilities.

Weapons proliferation has been a concern for many years. Recent studies by the Small Arms Survey at the Swiss Graduate Institute of International and Development Studies and other organizations suggest that the availability of weapons, optics, and ammunition on legal and black markets will continue to accelerate in the future.

[79] It remains possible that this could change. Innovation in the development and manufacturing of certain high technology systems may emerge in the private sector that greatly benefits the US defense establishment. An example is the emerging success of the Space Exploration (SpaceX) Corporation's strategy of creating a completely in house development of a family of space launch vehicles. NASA jump started SpaceX by awarding it one of the contracts to provide post-Shuttle resupply vehicles for the International Space Station (ISS), the Commercial Orbital Transportation System (COTS). Following recent successful resupply missions to the ISS, Space X is poised to offer NASA, the NRO, and the USAF a much lower cost family of space launch vehicles than the current quasi-monopoly launch provider, the United Launch Alliance, a consortium of Boeing Aerospace and Lockheed Martin. It is an open question whether acquisition processes (particularly requirements generation, OT&E, and contracting) will be able to adapt on a time scale that allows the services to absorb high technology innovations.

Furthermore, as developing economies and major powers such as Russia and China seek to modernize their military forces, the market for advanced small arms will expand.[80]

Several of the experts we worked with noted that the rise of 3D printing and ''open source" manufacturing capabilities will enable future enemies to construct their own copies of highly advanced weapons, optics, ammunition, and other key enablers. It is already possible for industrial 3D printers to create complex automotive and other machine parts by building up layers of metals and composite materials. Projections of 3D manufacturing suggest that in the near future it will be possible to produce complete mechanical and electronic devices directly in relatively inexpensive printers.[81] Entrepreneurs and venture capital have been moving into this technology space, anticipating the potential for customers to buy printers for home use that can create anything from home goods to the hottest children's toys using plans downloaded from the internet.

If it becomes possible for anyone to build weapons and other small arms components in a garage then the challenge becomes protecting the information (e.g., CAD files) that represents those physical systems. However, this may become difficult as the world becomes even more highly interconnected and cyberwarfare capabilities become more sophisticated. Ultimately, the chief objective might be to use highly specialized materials in small arms designs that are difficult to procure and/or easy to control.[82]

3. The Army will continue to rely heavily on technology as a force multiplier.

There is no doubt that the Army is the most technologically sophisticated fighting force in history. The reliance on technology is the result of several factors, including constraints on the size of an all-volunteer force that require technological approaches to force multiplication. Although investments in evolutionary versus revolutionary capabilities wax and wane according to budgetary priorities and technological opportunities, there is every reason to expect that the Army will continue to place a premium on technological dominance in the future.

4. The all-volunteer Army will persist, but the relationship between the Army and the American public will change in important ways.

The Vietnam draft put the limitations of manning the US Army through conscription in stark relief. By almost every measure, the transition to an all-volunteer force in the early 1970's has improved the caliber of our Soldiers. There is every reason to believe that the Army will continue to rely on volunteers as its bedrock.[83]

At the same time, cultural and demographic trends will continue to change the relationship between the Army and the American people. For instance, recent statistics suggest that at any given time less than 1% of the population will be serving in one of the service branches. This is unlikely to change in the future. Many observers have noted that such low rates of participation in the military will lead to a widening disconnect between the Army and the public. From the standpoint of small arms, very few Americans will have direct experience with the capabilities and

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[80] Advanced individual and crew service weapons may fall into the hands of a wide range of non-state actors including high performance criminal and terrorist organizations as the consequence of the collapse of a well-armed and wealthy nation state as the result of civil war and regime change. The diffusion of MANPADS and other heavy weapons into sub-Saharan African following the collapse of the Qaddafi regime is a case in point. Nigeria looms as a future prospect in this regard. So far these weapons have not shown up during France's intervention in Mali.

[81] For an example of this possibility see Henry Fountain, "Tools of Modern Gun making: Plastics and a 3-D Printer", *New York Times*, January 29, 2013.

[82] One interesting prospect is that future electronically enabled weapons such as the XM25, MANPADS and ATGMS could be manufactured with a built-in "stale date" that renders with weapon unusable. Alternatively, a next generation small arm may have a biometric devise to limit user access to that particular weapon.

[83] At the same time, it is possible that the training requirements for the "standard" infantry Soldier could become more and more SOF-like. Also, the cost of maintaining an infantry force will continue to rise with rising training and welfare benefits. A recent report by the Center for Strategic and Budgetary Assessments found that the cost per trooper in the active duty service has risen 46% over the past decade (Harrison, 2012). This figure excludes deployment costs associated with OIF and OEF which averages $1 million per combatant per year.

limitations of our weapon systems.[84] In fact, fewer Americans will have any familiarity with firearms. Private gun ownership has been on the decline for the past 30 years (Figure A-1).

The expansive growth of the video game industry will also have an effect on how Americans, particularly young recruits, think about small arms. On the one hand, portrayals of small arms in video games are designed for entertainment and rarely provide a faithful model of how real weapons work. A recent post on the popular website Reddit included a screen recording from the game Call of Duty in which a player blasts a tank clear onto the roof of a 10 story building by hitting it with a shoulder-fired missile. The tank is left completely intact following this gravity-defying engagement. Young people entering the Army, as well as those serving in its ranks, will find their expectations of how small arms should work shaped by video games and other media. On the other hand, multiplayer games often utilize sophisticated small unit tactics (though the effects of those tactics may not mirror real-world combat). Paradoxically, Soldiers might enter the Army with little to no experience with ''skill level one'' tasks such as weapons maintenance and marksmanship, but a greater degree of experience with tactics.

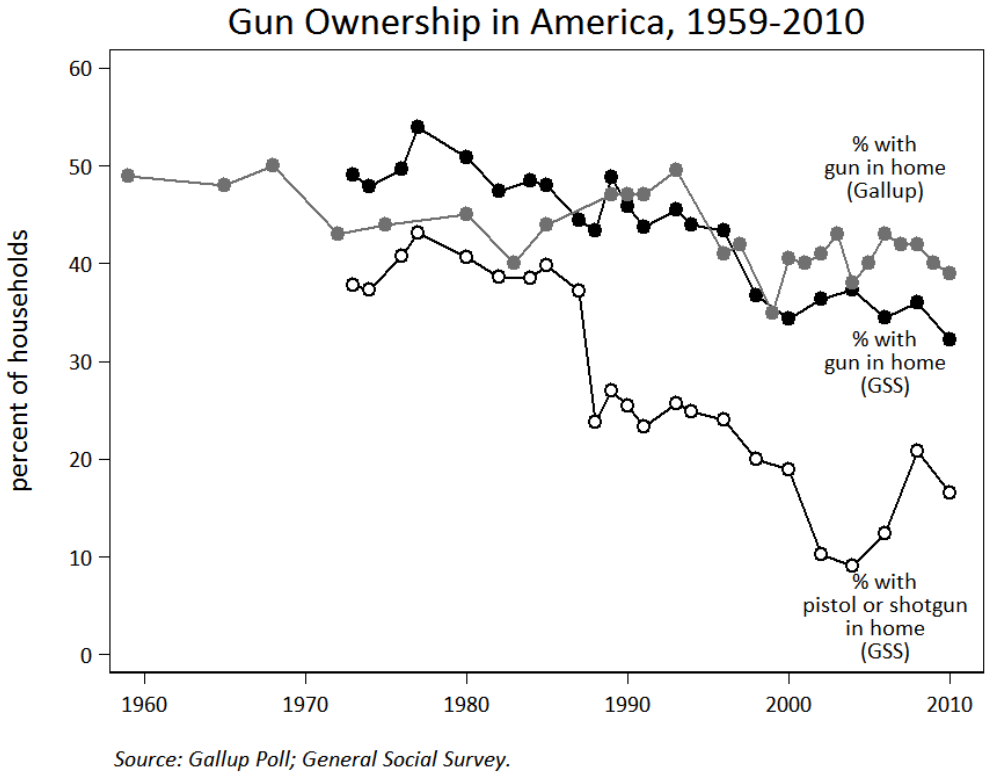

Figure A-1: Percentage of US households owning firearms from 1959-2010 (Klein, 2012).

Another trend that will shape small arms is the growing availability of raw battlefield imagery on the internet. The Army has lost its ability to act as gatekeeper over the flow of video and photographic information, much of which is uploaded by Soldiers in the field. Depictions of the carnage that modern weapons can create are readily available and often presented without sufficient context. Most Americans - civilians and Soldiers alike - rightly recoil from scenes of death and destruction. However, the lack of military experience among the populace coupled

[84] On the other hand, there has a wide diffusion of the AR15-class assault rifle in its “civilian” semi-automatic form, a phenomenon now subject to a major domestic debate as to whether this class of weapons should be banned outright following a number of recent mass killings where this class of weapon played a prominent role.

with declining participation in hunting and other shooting sports could create significant public resistance against ''bringing a machine gun to a knife fight". This could, in turn, constrain the design of future small arms.[85]

5. Peace will not break out, and the Army will not cede its ability to fight and win on any terrain.

We do not include a scenario that envisions a dramatic improvement in the global security environment .[86] Most defense experts agree that the world will remain beset by conflicts of some magnitude well into the future, though the exact role of the US in future conflicts is uncertain. It is unlikely that swords will be beat into plowshares by 2042.

There is also nothing to suggest that the Army will turn its back on any geographic region, to include the Arctic. The Army Capstone Concept and other doctrinal publications assume that the Army will retain its ability to fight and win on any terrain. While we have been highly focused for the past 10 years on Iraq and Afghanistan, many emerging threats in other parts of the world have begun to occupy the national debate. The transition of the Army to a regionally-aligned force structure underscores the notion that leadership sees the potential for operations in traditional hot spots as well as emerging strategic regions in Asia, Africa, and South America.

Axes of Uncertainty

The future of small arms technology in 2022-2042 will be shaped by a rich web of interconnected and dynamic factors. While many sources of uncertainty will be in play, there are certain aspects of the ''small arms ecosystem" that can be anticipated with a fairly high degree of confidence. These trends form a common foundation that will play out in all of the alternate futures explored below, though the implications will often depend critically on matters of a less predictable nature.

1. Will a peer-competitor emerge to challenge the United States, creating a strategic imperative for investments in modernization and revolutionary capabilities?

The nature of the threats faced by the Unites States in 2022-2042 has unclear implications for how we think about future investments in small arms. Historically, the defense budget has been driven by the perception of the American political leadership and public of the magnitude and urgency of the international threat. To provide a bit of context, since World War II the defense budget has averaged 4% of GDP, with greater expenditures during the Cold War and reductions in appropriations in the 1990's as the nation reflexively responded to the demise of the Soviet Union (Figure A-2).

The critical point is that budgets respond to perceived strategic imperatives. For example, the assumption that the end of the Cold War would allow for a ''peace dividend" led to reductions in force and constraints on acquisition (to include research and development) that were reversed following the September 11th terrorist attacks that sparked the global war on terror. If the national consensus is that the nation is under a new threat above and beyond radical Islamic terrorism then more revenue will be invested in force modernization and development of new capabilities.

While the budgetary effects of the perceived security environment appear fairly predictable, it is more difficult to forecast the scale of potential future threats and the nature of how these threats might be perceived. Many defense experts argue that conflict with a large, technologically sophisticated competitor such as China is plausible. There is certainly a basis for conflict with the Chinese in the 2022-2042 time-frame. For example, the United States might be drawn into an Asian conflict with China as the result of a long-standing extended deterrent

[85] The societal phenomenon described above may be one of a number of reasons why the high technology democracies may invest in robotized combat systems with increased autonomy.

[86] While we do not envision a scenario in which lasting world peace emerges over the next 30 years it is worth acknowledging that historical analysis suggests a steady and substantial decline in domestic and interstate violence (Pinker, 2011). Unfortunately, these historic trends could be shattered, say by the outcome of a regional nuclear war between India and Pakistan or a second Korean War.

commitment to one or more of China's neighbors. China may become more assertive in using military power in distant locations outside of Asia as result of its major resource investments in Africa and Latin America. This competition for vital resources and competing interests in Africa and other regions could drive significant, and possibly armed, conflict with other major powers such as India. On the other hand, the economies of the United States and China are mutually dependent in ways that are entirely unlike our relationship with the Soviet Union during the Cold War. Economists have argued that any Sino-American military confrontation would result in mutually-assured economic destruction, and is therefore unthinkable.[87]

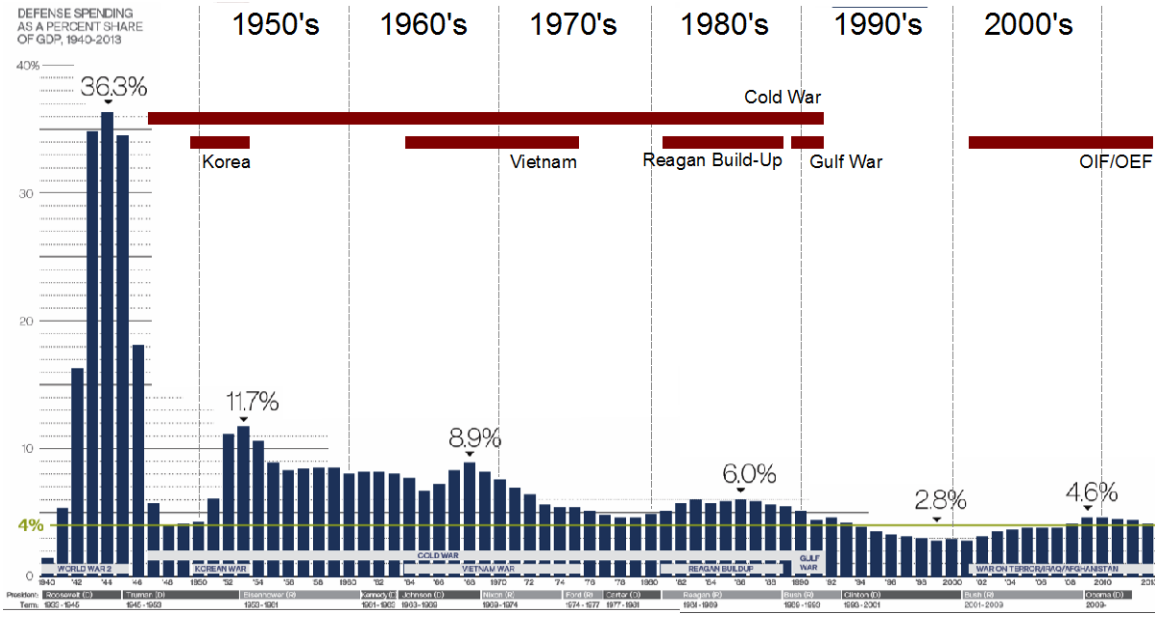

Figure A-2: US defense expenditures as a percentage of GDP, 1940-2010 (Levinson & Leuthy, 2012)

Noteworthy is the near-certain prospect that the United States will become a hydrocarbon surplus power during the 2020s while China has and will remain a massive importer of hydrocarbons through the period of this forecast. While China stands as an emerging near-peer challenge, the Russian leadership continues to see the Russian Federation as a counter-weight to the US and have embarked on an effort to build increasing close strategic ties with China to affect the emergence of a "multi-polar world". China has undertaken major programs to modernize the full spectrum of their armed forces including their ground forces while developing a robust military research and development capacity. Although the new Putin administration has an ambitious plan to modernize the Russian Armed Forces, those plans are hostage to the global price of oil and natural gas, the obsolescence and corruption in the defense sector, and inability to shift from a low quality conscription to a well-trained professional force.[88]

Conflict with either China or Russia is certainly possible over the next 30 years, but is by no means certain. The question is whether the United States will perceive enough of a ground force threat from these nations (and other developed or developing powers) to dramatically reshape investments in ground combat systems, including small

[87] This was the similar argument made by the "peace movement" prior to World War I. See Bloch, op.cit,, and Norman Angell, "The Great Illusion, A Study of Military Power in Nations to their Economic and Social Advantage", Simpkin, Marshall, Hamilton, Kent & Co., London 1910,

[88] For a comprehensive forecast of the Russian Armed Forces' modernization plans and prospects see Pallin (2012). This analysis points out that the military weakness of the Russian Armed Forces in the Far East in the face of China's modernizing military and transportation infrastructure has assured Moscow's continued reliance on nuclear weapons to compensation for that inferiority – a strategy not unlike NATO's approach in the nineteen fifties.

arms and related technologies. The alternate futures will explore a range of potential outcomes related to this question.

2. What operational tempo (OPTEMPO) will the Army be called upon to maintain?

While preparation for a renewed superpower confrontation is one factor that will influence the future of small arms technology, another area of uncertainty is the baseline level of operations that the Army will be called upon to maintain. As we have seen over the past 10 years, and to a somewhat similar extent during the Korean and Vietnam wars, when the Army is engaged in a high OPTEMPO it tends to adopt a more near-term focus on satisfying the demands of current operations.

Revolutionary innovations in technology, force structure, and doctrine receive greater emphasis in periods marked by less frequent and less intense combat. For example, the novel (but ultimately impractical) Pentomic Army concept was primarily explored during the years between Korea and Vietnam.

Looking forward to 2022-2042, it is difficult to anticipate with certainty whether the US will settle into a sustained period of sporadic operations with space for experimentation with new concepts and technology, or if we will be required to send forces overseas to maintain stability and forestall emerging threats. Projections of increasingly frequent and severe natural disasters point to a future in which the unique capabilities of the US Army will be called upon routinely to assist in humanitarian relief and stability missions. In a related vein, the shift to a regionally-aligned force structure, which will be complete by 2015, could increase the stimulus for American involvement in regional troubles. On the other hand, the American people have limited tolerance for long-term military operations, and public and Congressional pressure on Executive leaders has a significant throttling effect on the frequency and scale of overseas operations.[89] The alternate futures presented below explore the consequences of OPTEMPO on investments in small arms technology.

3. Will domestic forces unrelated to the external security environment exert a significant influence on investments in small arms technology in 2022-2042?

At the end of the day, research and development of new small arms systems is limited by the size of the defense budget. As noted above, the external security environment provides one powerful source of stimuli that shape the scale of investment in national defense. However, budgets are also influenced by domestic issues and priorities. For example, concern over massive budget deficits and the size of the federal debt drove the 2011 enactment of the Budget Control Act, which mandates automatic cuts to national defense of approximately $600 billion over the period from 2013 to 2021 unless Congress acts on a comprehensive deficit reduction plan.

Even if sequestration is avoided, defense budgets are expected to decline as the government re-prioritizes funding after 10 years of war. In particular, many have called for renewed investment in infrastructure and an expansion of support for domestic energy production. Assuming that projections of increasing severe weather bear out, more funds will be needed to provide for disaster relief and projects to increase the resilience of the electrical grid and other vital infrastructure. Drought conditions are also projected to grow over the next century, leading to larger and more frequent forest fires and damage to the US agricultural industry. Finally, as life expectancy grows the percentage of the budget allocated toward Social Security and especially Medicare solvency will increase made most acute in the 2020s by the aging demographic cohort, the “Baby Boomers”.

Many of the internal forces outlined above are predictable on the basis of demographics and other data. Other possibilities, such as the outbreak of a flu pandemic or a chronically underperforming economy, are less certain. However, it is quite clear from historical precedent that domestic issues will shape budget priorities for the

[89] In this regard the “Iraq-Afghan Syndrome” has largely replaced the “Vietnam Syndrome” as a widely share view that the direct engagement by significant US military forces, especially ground forces, abroad should be highly circumscribed. This view does not exclude the continued use of SOF and their robotic enablers to conduct targeted killing operations against Al Qaeda and its franchises.

foreseeable future. The alternate futures presented below explore several possible scenarios for how this influence could affect small arms technology. The authors of this study acknowledge that the relationship between the broader national security scenarios described below and the small arms ecosystem may prove to be subtle if not perverse. After all, at the height of the Cold War during the nineteen fifties, little interest was shown by the Army and Marine Corps in modernizing its small arms when the overwhelming emphasis was the attempt to adapt both ground forces for the prospect of extensive nuclear weapon use on the battlefield.

The Scenario Framework

The intersections among the axes of uncertainty colored by assumptions about the world in 2022-2042 create a multi-dimensional space of alternate futures. From this space we selected four narratives that cover the frontiers of what might be and that prompt challenging questions about the future of small arms technology.

Cold War II

In this future, the United States is locked in a geopolitical standoff with China and a resurgent Russia.[90] OPTEMPO is low, but all sides maneuver through proxy wars fueled by proliferation of advanced small arms and related technology. High end weapon modernization and revolutionary capabilities are an urgent priority with a mixed impact on the small arms environment. The SOF community may be the main driver with “Big Army” focusing on AFV, ISR, fire support systems, and robotic development and investment.

Global Footprint

In this future, the United States is engaged in a continuous string of low-intensity conflicts and relief operations. At home, political support for large defense budgets has fallen, and the Army is forced to adopt a near-term emphasis. Coalition operations and leveraging of off-the-shelf resources have become the order of the day with a likely stagnation of small arms developments.

Turning Inward

In this future, constrained by an unstable economy and beset by domestic security challenges the United States has pulled back from the global military engagement that characterized the early decades of the 21st century. Many Soldiers have unexpectedly found themselves "deployed" to their own back yards. The lack of a military demand signal and constrained resources lead to a stagnation in small arms development with the United States, with the possible exception of less-than-lethal technologies for crowd control. Most new developments in this regard emerge from foreign powers especially those that take on a more regionally assertive posture if only to compensate for the American recessional from its prior military commitments.

Standing in a Tinderbox

In this future, the world has become a dangerous and unstable place. Regional wars rage over access to clean water and other vital resources, while the Unites States, Russia, and China spar over the Arctic. Chemical, biological, and radiological weapons have been used on battlefields in Korea and the Middle East. In response, the United States has invested heavily in modernization and revolutionary technologies to adapt to an operational environment that seems primed to explode. The US desire to maintain an overmatch at all echelons of combat drive a vigorous effort to develop and deploy a next generation of small arms for both human and robotic infantry.

[90] As noted previously the resurgence of Russia assumes that the second era of Putinism leads to both a modernization of the Russian economy and its armed forces.

Cold War II

The United States is locked in a geopolitical standoff with China and a resurgent Russia. OPTEMPO is low, but all sides maneuver through proxy wars fueled by proliferation of advanced small arms and related technology. Modernization and revolutionary capabilities are an urgent priority.

It's 2042, though many historians have argued that the global political climate feels more like 1982. Others point out that in the 80's we only had to contend with one other superpower, not two. China and Russia have become formidable competitors on the global stage, though each nation presents unique strategic challenges for the United States. Tensions among the three nations are high, spurred by increased competition for vital natural resources. Direct military confrontations are rare, but proxy wars are common throughout Africa, Southeast Asia, and South America. NATO has found renewed purpose in the Arctic, as receding ice sheets have uncovered a treasure trove of oil, natural gas, and minerals.

Throughout the 2020's and 2030's forecasts by western observers of a "Chinese Century" seemed prescient, as the Chinese economy expanded on a wave of measured liberalization and a national mission to capture dominant shares of emerging markets for nano-scale manufacturing and renewable energy technologies. The potential for conflict with the United States was clear. However, most experts on Sino-American relations were caught off guard by the willingness of the Central Committee to use military assets in support of economic objectives. Beginning as early as 2014 the People's Liberation Army (PLA) had pursued an ongoing program of modernization and training, resulting in a standing ground combat force of over one million men and highly capable reserves of approximately 500,000 additional Soldiers.

There is little doubt that the technological capabilities of the regular Army are equal to that of the US and her allies. Even the Chinese reserves boast small arms, robotics, and sensor systems that exceed most other nations. The Chinese military-industrial base has evolved a highly efficient and well-resourced research and development pipeline that supplies the force with regular upgrades to existing systems and pursues leap-ahead capabilities based on extensive analysis of competing US capabilities. The PLA also benefits from western design and engineering concepts "liberated" by a sophisticated cyber-espionage apparatus.

While the Chinese occupy most of the national security debate within the US the Russian Ground Forces are also a significant concern. By the early 2020's it became apparent to most Russian leaders that it would be foolish to beggar the nation in a vain attempt at simultaneously matching the Americans in military technology while competing with the Chinese in sheer numbers of men under arms. The resulting strategy focused on a buildup of naval, space, and cyberwarfare capabilities, with selective modernization of Russian Special Forces, marine, and airborne units to support force projection in the Arctic and exert pressure on NATO and the PLA.

To expand influence and feed the domestic defense industry the Russians also sold massive amounts of small arms, precision indirect fire, and man-portable air defense systems to developing nations throughout Africa and South America. Most of these systems were inferior to western military technology, but represented a revolution in the lethality available to warlords, terrorists, and transnational criminal organizations. By the mid-2030's this had become a significant security problem for the US military.

In response to the rising challenge from China and Russia the US defense budgets steadily increased to around 6-7% of GDP by 2028 and have remained at those levels through FY42. Much of this funding has gone to buildups of naval, cyber defense, and space systems, though the threat of a major land war against a numerically superior enemy has kept Army modernization efforts well-funded. Research and development has also expanded as political and military leaders have increasingly turned to technology for the means to remain dominant in the global arms race.

Now, in 2042, the United States Army finds itself in the familiar position of preparing for a major war that seems inconceivable given the dire consequences. Concerns over escalation have made combat deployments of more than two brigades exceedingly rare. Of course, large numbers of Soldiers are forward deployed to Eastern Europe, Korea, and North and East Africa to protect regional allies and vital US interests. To counter Chinese and Russian influence US forces also routinely advise and train local military forces in the use of advanced weapons, enablers, and ammunition supplied by American and European arms manufacturers.

Impact on the Small Arms Ecosystem

The scenario assumes the United States is under the twin pressure of China and Russia as aggressive near-peer competitors. This global future is an acute version of the high of the Cold War when the United States viewed Soviet Union and China as close allies. Even though the US has sustained an extraordinary level of peacetime spending, R&D investment in small arms may be considered a secondary priority not unlike the nineteen fifties. On the other hand, there will be significant resources available for small arms development given their tiny investment footprint compared to the likely very investment being made in all arms robotic fighting systems.

Global Footprint

The United States is engaged in a continuous string of low-intensity conflicts and relief operations. At home, political support for large defense budgets has fallen, and the Army is forced to adopt a near-term emphasis. Coalition operations and leveraging of off-the-shelf resources have become the order of the day.

It's 2042, and the US Army is deeply engaged in low-intensity operations and relief missions around the world. Speaking to the press from his command post in Djibouti, the regional commander of AFRICOM characterized the global situation as, "a giant game of whack-a-mole. Every time we solve one humanitarian crisis or take out one tin pot warlord three more pop up." Over the past 30 years, the Army has supported various international relief missions while managing a constant background hum of tension throughout Africa, the Middle East, and South America.

Throughout the 2020's and 2030's accelerating climate change made global weather patterns highly volatile, with "100 year storms" happening every 3-5 years. The developing world has borne the brunt of the uptick in natural disasters. Population density has been rising throughout the developing world for the past 30 years, leading to crowded urban centers, many located on coastal lands frequently hit by major hurricanes and tsunamis. The number of people living near active geological fault lines has also increased, leading to massive casualties and

economic destruction from earthquakes. Drought and desertification in Africa and Asia have led to famine and created a tide of refugees fleeing civil unrest and wars fought over water and arable land.

All of this upheaval has created a dynamic mission set for the US Army. At any given point Soldiers are deployed in missions ranging from calming civil unrest during disaster relief missions to rooting out tribal militias engaged in ethnic cleansing. For the most part, enemy fighters are lightly armed and poorly trained compared with US forces. However, engagements frequently occur on urban terrain under the ever-present eye of the international press (including many local eyewitnesses broadcasting to the world with smart phones). Furthermore, enemy forces often shield themselves with noncombatants and employ child Soldiers, creating significant tactical problems for squads.

Despite daily media reports on food riots, tsunamis, and ethnic conflict most Americans believe the United States itself to be secure. Military confrontation with China never materialized the way many feared in the early part of the 21st century, and the discovery of massive reserves of shale oil and natural gas in the continental US coupled with the European's move toward renewable and nuclear power removed most points of friction with traditional competitors. As a result, political support for large-scale defense budgets has fallen dramatically. From 2022-2042 the budget for the Department of Defense gradually held steady between 3-4% of GDP. The Army has been well-funded to support its high OPTEMPO. However, the cost this global footprint has led to an emphasis on near-term investments to sustain current operations and maintain current systems.

"Leveraging" has become a cornerstone of defense policy. Missions that cannot be handled entirely by Special Forces or support units invariably involve some degree of partnership with allies and regional forces. In fact, one more than one occasion the Army has found itself operating with odd bedfellows. For instance, in 2030 Soldiers of the 10th Mountain Division found themselves fighting alongside Chinese infantry during a U.N. peacekeeping operation to restore order to North Sudan.

The strong emphasis on joint and international partnerships has led Army acquisition staff to look toward COTS technology or systems that afford cost-sharing with other services or allies. This has affected every facet of weapon systems procurement, from the kind of small arms the Army purchases to the kind of robotic systems that have been incorporated into squads. Investments in new weapons research and development focus on niche applications that cannot be leveraged from partners or the defense industry. Where new systems are sought from the science and technology community, the emphasis is on durable, ''multi-use'' systems that meet near- to mid-term needs.

Impact on the Global Small Arms Ecosystem

This security scenario will likely generation operational requirements to powerfully accelerate the development and deployment of “less than lethal” small arms and crew serviced weapon systems. Basically, there will be the pressure to develop small arms that having features of the Star Trek “Phaser”. Furthermore, the SOF community will be a dominate player in this political military environment and the nature of targeted engagement will drive interest in maintaining combat overmatch at the squad and platoon level. Major efforts are likely to develop increasingly autonomous aerial and ground robotic combat systems to support small squad-level operations. Most of the military operations will not be in a high threat air defense environment, many of the squad robotic enablers will likely be UCAVs with high persistence and/or micro-system with self-initiating swarming attributes.

Turning Inward

Constrained by an unstable economy and beset by domestic security challenges the United States has pulled back from the global military engagement that characterized the early decades of the 21st century. Many Soldiers have unexpectedly found themselves "deployed" to their own back yards.

It's 2042, and the strategic focus of the United States military has turned inward. Constrained by an unstable economy and beset by domestic security challenges the nation has pulled back from the global military footprint that characterized the early decades of the 21st century. At the same time, the National Guard has been stretched in responding to natural and man-made disasters. Legal constraints on the domestic use of regular Army forces have weakened, and thousands of Soldiers have unexpectedly found themselves ''deployed" to their own back yards.

Many historians and defense experts trace the beginning of this pullback to the rise of increasingly sophisticated terror and cyber attacks against domestic targets that began in the early 2020's. Faced with budgets constrained by a chronically weak economy saddled with massive debt these attacks on the homeland forced realignment away from foreign operations. Others experts emphasize the public backlash against using US forces as ''world police" following a sharp rise in deadly attacks against Soldiers in countries that most Americans could not find on a map. Observers also note that the increase in super-storms and severe drought throughout the 2020's and 2030's created added stress that sparked frequent and large-scale civil unrest.

The new security challenges facing the US at home came to a head during the 2038 Singapore Flu, a global influenza pandemic that killed over 175 million people worldwide from 2038 through 2040. The US casualty rates were low compared with other industrialized nations owing to a strong and coordinated response led by the federal government. Flight bans and quarantine procedures were instituted at airports across the country to control the spread of the virus, and non-essential economic and security activities were curtailed whenever possible.

During the outbreak the Army found itself called upon to provide the security backbone needed to enforce an unprecedented public health operation. Quarantine zones, medical facilities, and transportation hubs were all secured by the National Guard. Reserve forces were called upon to supplement the Border Patrol in turning back waves of refugees at the Mexican border. The use of Army assets inside the US culminated in 2039, when Congress temporarily suspended the *Posse Comitatus* Act to allow regular units to deploy in support of security operations, including crowd control at violent protests that were breaking out in cities nationwide.

The focus on the home front has led to a marked reduction in overseas deployments. When the Army does send troops into other nations it often relies on Special Forces and light infantry units that can deploy rapidly and complete the mission within weeks rather than months. For the most part, overseas operations focus on eliminating terrorist cells and preempting threats from emerging regional powers in the Middle East and Africa. Units are trained and equipped to deliver precise and overwhelming attacks against hostile targets. Collateral damage is avoided whenever possible, but reluctance toward long-term operations drives commanders to use the most expedient tactics for the situation at hand. This trade-off has delivered ample grist for anti-American propaganda on the internet and in the foreign press.

The challenging domestic environment has put most defense investments on the back burner. Annual appropriations have ranged from 2-3% of GDP from 2022-2042. The Army's share of the budget has remained robust, but is largely dedicated to paying for current operations and making targeted investments in new technologies to support the expanded mission at home. National Guard modernization has become a priority, reversing a trend that had prevailed throughout its history. As the nation has pulled back from foreign entanglements the requirement for standardization with NATO has become less of a constraint on new small arms technologies. Instead, the Army has taken an open-armed approach to sourcing new systems to meet a unique and unprecedented mission set.

Impact on the Small Arms Ecosystem

With the exception of the development of less than lethal system to deal with the threat of domestic violence, small arms development will likely stagnate in this national security scenario. Most new developments of small arms will likely emerge outside of the United States. A number of major powers including China, India, Turkey and Brazil may take on regional and global policing missions which call for further innovation in the extant generation of small arms capability.

Standing in a Tinderbox

The world has become a dangerous and unstable place. Regional wars rage over access to clean water and other vital resources, while the Unites States, Russia, and China spar over the Arctic. Chemical, biological, and radiological weapons have been used on battlefields in Korea and the Middle East. In response, the United States has invested heavily in modernization and revolutionary technologies to adapt to an operational environment that seems primed to explode.

It's 2042, and to many the world seems to be coming apart at the seams. Regional wars rage in many parts of the world, and desperate nations have shed traditional qualms over the use of chemical, biological, and radiological weapons. The nuclear genie remains in the bottle, but defense experts no longer find the likelihood of a "small-scale" nuclear exchange unthinkable. For the first time in close to 50 years, the American Federation of Concerned Scientists have placed the hands of the "Doomsday Clock" at three minutes to midnight.

Battles over access to water and other vital resources have become commonplace over the past 20 years. Overpopulation, demographic shifts, and chronic worldwide drought have brought even historically friendly nations into conflict. The violence scales with the economic and technological sophistication of the combatants. At the low end, ethnic groups in the Balkans and central Africa spar with 2015-era small arms derived from the AK47 and Chinese Type 95. At the regional level, the Arabs and Israelis, as well as the Pakistanis and Indians, have slaughtered each other with ruthless efficiency using sophisticated weapons with advanced optics and enablers. The global trade in small arms has exploded with the advent of efficient 3D printing and other small-scale

manufacturing capabilities that allow anyone with a stolen weapon design to build advanced technologies literally in a garage.

Despite calls for a return to protectionism, the United States has remained engaged in operations around the world. Combat deployments are fairly common, and most active duty personnel have seen at least one deployment as part of NATO or other coalition-based missions. The spread of weapons of mass destruction following the collapse of North Korea in the mid-2020's has put US forces in the field at real risk from chemical, biological, and radiological attack. Soldiers are equipped with advanced personal protective ensembles, and have had to conduct missions encapsulated in this gear.

US involvement in operations in the Balkans and Korean peninsula has further strained relationships with China and Russia that had been steadily eroding since the early 2020's. All three nations have laid claim to vast new reserves of oil and other natural resources that have been discovered in the Arctic. The United States has also been called upon to support territorial claims by Norway and Canada. While confrontations to date have been limited to naval and air maneuvers the US Army has been tasked with preparing for ground operations at the top of the world.

Standing in a tinderbox facing a thousand lit matches, the US has held defense expenditures at 6-8% of GDP for the past 20 years, with occasional surges to 9-10% to handle contingency operations. Despite (or perhaps because of) the violent security environment, the number of Americans volunteering for the Army has not increased since the early years of the 21st century. Therefore, the Army has directed significant investments towards small arms and other technologies that can maximize the ability of its squads to remain dominant against numerically superior enemies that might be capable of employing near-peer or peer systems.

Impact on the Small Arms Ecosystem

Similar to the Cold War II scenario, this national security scenario will likely accelerate the demand for very high technology solutions to the various security dilemmas of the United States. Given that WMD has been used in a number of regional conflicts, there will be a major push to developed Soldiers with high survivability in that "dirtied" battlefield. This suggests that there be the simultaneous push to develop the exoskeleton enabled and armored "Starship Trooper" as well a full spectrum of robotic enablers. It is highly likely, that the traditional kinetic weapon, the assault carbine, will be replace by weapons discharging HE warheads (guided and unguided) and directed energy weapons.

A Hybrid or "Surprise Free" Future[91]

The four alternative futures presented above represent the out edges of a four cell matrix with one axis moving from order to disorder and the other moving from the weight of influence between state and non-state actors. The actual course of human history during the next forty years will likely be a mix of many of the major features identified in by the alternative futures. Therefore, we close this section with a fifth, hybrid, scenario that reflects a "surprise free" projection between the four scenarios that were used in the ideation workshop described in this Appendix. Although this scenario was not put to workshop participants, we hope it provides additional food for thought as the Army continues considering the future of small arms technology.

From a national security perspective, the most salient feature of this scenario is the likely dynamic and complex rivalry between the United States and China. Put simply, there may emerge a "cool" war between Washington and Beijing with both try to find a balance between deterrence aka containment and cooperation on wide range political, economic, and environmental issues. Although China will likely emerge as a near-peer military power to

[91] Herman Kahn, the noted futurists and early developer of planning scenarios during the sixties and seventies, developed the concept of a "surprise free" future during the mid-1960s. See Herman Kahn & Anthony J. Wiener, *The Year 2000: A Framework for Speculation on the Next Thirty-Three Years*, The MacMillian Company, New York, 1967

the United States by the 2020s, the leadership of the Chinese Communist Party (CCP) will face daunting domestic challenges. First is the challenge of shifting the economy away from its dependence on exports to domestic consumption. Second is addressing the deteriorating national environment including a crisis in the lack of potable water. Third is dealing with the emergence of an increasingly media savvy middle class and labor movement. Fourth is dealing with demographic trends that might cause China to get old before it gets rich, caused by the unfavorable 2030s shift in the ratio between the elderly and younger work force resulting from the one child policy. Fifth, the problem of high level and massive corruption of the Chinese leadership will further undermine the legitimacy of the CCP. Finally, there is the risk that nationalism will be exploited by the leadership as an alternative ideology to the obsolescent concepts of Marxism and Leninism. Put simply, the internal political economic system of authoritarian (crony) capitalism will have features of Kaiser Wilhelm II's Germany, a single party aristocracy sitting on a cauldron of dynamic social, economic, and political change fueled by 21st century media enmeshed in the global information ecology.[92]

During the 2020s the Chinese regime will increasingly rely on nationalism as the means to sustain its right to rule. This will lead to increasing assertiveness in satisfying Chinese interests, especially over unresolved territorial disputes with its Asian neighbors. Although they will have a large trading relationship, China and India will likely become major geostrategic rivals. This rivalry will be fueled by China's continued territorial disputes with India over the status of the latter's northeast territories as well as whether China will carry out massive water diversion projects on the Tibetan Plateau. China's continued support for a nuclear-armed Pakistan will be a source of tension. Finally, there will be a rivalry for influence over Southeast Asia, especially over resource rich Myanmar (aka Burma).[93] Unclear is whether China and India will emerge as rivals or collaborators in the Persian Gulf region. Unlike the United States both will have become very dependent upon the free flow of petroleum and national gas from the PG region. Another zone of competition and/or cooperation will be in the acquisition of resources from Africa.

Russia will remain an energy superpower, although its national income stream may be seriously constrained from time to time. This fiscal dependence on the sale of hydrocarbons will be vulnerable to major changes in the global hydrocarbon supply and demand balance. Any sustained downturn in global hydrocarbon prices will likely put serious fiscal pressure on future budgets for the Russian Armed Forces.[94] As noted above, Russia faces several security challenges simultaneously, containing the rise of radical Islam in the Caucuses, sustaining a credible military balance in its Far East with China and remaining a significant strategic player in the Greater Middle East. Further, Russia's capacity to successfully export advanced armaments will be challenges by the rise of China, India, Turkey, South Korean and possibly Brazil as major high technology arms exporters. This is aside from competing with the United States and Europe for the military export business.

The EU will emerge with a two-tiered economic structure with an increasingly federal Eurozone dominated by Germany with the UK, Sweden, Turkey and other significant peripheral states formally or informally operating outside of this currency zone. NATO Europe's capacity to project military power even with US military assistance will be very limited with the current French operations in Mali as an example of the outer edge of that capability. Not surprisingly, the cohesion of the Atlantic Alliance will rely less on traditional security issues and more on

[92] For a discussion of this phenomenon see Gideon Rachman, "The shadow of 1914 falls over the Pacific Ocean", *Financial Times*, February 5, 2013.

[93] See David Pilling, "China's pipeline marks the scramble for Myanmar", *Financial Times*, January 31, 2013 for a discussion of the strategic implications of the soon to be completed natural gas and petroleum pipelines from the coast of Myanmar to Kunming, China.

[94] For a discussion of this strategic vulnerability see Stefan Schultz and Benjamin Bidder, "Once Mighty Gazprom Loses Its Clout", SPIEGELONLINE, February 1, 2013.

matters dealings with the global trade, financial, and economic system and the continued threat of radical Islamic terrorism.[95]

The threat from radical Islam will not likely subside during this forecast even if the Al Qaeda core group is totally destroyed. Radical Islam as a political movement will have powerful transnational features not unlike communism while feeding off of local historical, sectarian, racial, and economic grievance. Given the likely instability in the Middle East and North Africa (MENA) region, there will be future opportunities for aggressive spin-offs of Al Qaeda to gain control if only temporary of failing if not failed states during this period of great social, political, technological and economic change.[96] Another major source of tension within the MENA region will be the continued sectarian and regional rivalry between Saudi Arabia and Iran where it is plausible both may be nuclear-armed. While it is unlikely that another source of regional tension will be resolved with the resolution of the Israeli-Palestinian struggle.

Nuclear-armed regional stand-offs will continue in South Asia between Pakistan and India and North Korea will remain a nuclear-armed geostrategic client of China. The United States will be successful in convincing Japan and South Korea not to convert their civilian nuclear power infrastructure into weapons programs. This will require a continued and robust extended deterrent commitment. (See below)

Finally, a very important geostrategic and geo-economic feature of the early 21st century will be the rise of a number of major powers that will include Brazil, Nigeria, Turkey, South Africa, Indonesia, Iraq, and possibly Iran. Many will present the United States with the opportunity to collaborate on a wide range of regional security interests while some may continue as security challenges.[97]

The United States will remain first amongst equals militarily, economically, and technologically. It is now likely that the United States will become a net hydrocarbon exporter by the early 2020s in contrast to the status of China, India, Japan, and the EU (British Petroleum, 2012).[98] This energy supply side revolution will stimulate an industrial renaissance while radically improving the US trade balance and facilitating long-term solutions to the national debt and maintaining solvency of entitlement programs. At the same time, climate change will continue to reshape US weather patterns, with damage from severe drought and super-storms becoming routine. These demand signals will drive a massive investment in infrastructure.

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[95] For an analysis of the strategic and operational implications of the defense reductions in NATO Europe see F. Stephen Larrabee, et.al., *NATO and the Challenge of Austerity*, RAND National Defense Research Institute, MG-1196-OSD, 2012.

[96] For an analysis of this phenomenon see James Blitz and Roula Khalaf, "The jihadi hydra", *The Financial Times*, February 4, 2013 and Greg Miller and Joby Warrick, "Al-Qaeda divided but still a danger", *The Washington Post*, February 4, 2013. For a more sanguine view see Peter Bergen, "Should we still fear Al Qaeda?", CNNOpinion, February 3, 2013.

[97] A grand bargain between the United States and its allies with Iran to freeze if not roll back elements of Iran's nuclear material production capacity may produce the paradoxical outcome of greatly enhancing Iran's prospects as a major if not dominant power in the Persian Gulf region. Such an agreement would likely lead to the rapid end of most economic and arms sanctions with both China and India aggressively expanding their energy ties with Tehran. The former will jumpstart the Iranian economy. Both will jumpstart the Iranian economy, and the former might sell ever more sophisticated "conventional" weapons including a wide array of precision guided munitions (PGMs); therefore, potential military opponents such as Israel and Saudi Arabia may face an Iran well-armed with a large arsenal of long-range cruise and ballistic missiles capable of conducting strategically significant attacks without the resort to the use of WMD.

[98] The United States will become even more resilient to future petroleum price shocks if heavy duty trucks and most urban buses and delivery vehicles shift to CNG/LNG fuels or second generation biofuels.

The US national security strategy will follow a neo-Eisenhower model with its emphasis on strategic and regional deterrence, fiscal sustainability, and special operations and counterterrorism.[99] Defense spending will likely stay just under 3% of GDP between 2020 and 2040. The configuration and priorities of the US national military posture will remain relatively unchanged during the period of this forecast and will have the following major elements:

- Priority on maintain a very high performance counterterrorism capacity including the capacity to conduct targeted killings as part of a comprehensive strategy of homeland defense.[100]
- The maintenance of a large[101] high performance Army and Marine Corps to conduct rapid intervention operations larger in scale to the French intervention in Mali while dealing with more lethal local threats.[102]
- Maintenance of air and sealift capabilities to support the above ground force posture.
- Maintenance of a high performance capacity to support selected and sustained FID operations.
- Sustain an Indo-Pacific oriented USAF and USN that can act as a deterrent shield to China and potentially hostile nuclear-armed regional powers such as Iran, North Korea, and Pakistan?
- Sustain a smaller but diverse nuclear arsenal.
- Continue extended deterrent commitments to key traditional and emerging allies such as Israel, Japan, South Korea, NATO Europe, Australia, India and members of ASEAN, Philippines, Vietnam, and Singapore.
- Continue investment to maintain a dynamic advantage in space and cyberspace during peace and war.[103]

By 2040, 60% of the global population will be urbanized. Even with the best case scenario, the average global temperature will have increase by 2degrees Centigrade. Overall, the global economy will continue to grow at an average of 3-4% with no setbacks on a scale similar to the Great Recession. This will be fast enough to sustain the emergence of massive and urbanized middle classes in MENA, Latin America, Africa, and Asia. Further, it will not lead to any slowdown in the scientific and technological dynamism of the human race. Likely major innovations will include: a) a third industrial revolution of additive manufacturing and robotics; b) nanotechnology materials including super-hard and flexible concrete; c) major advances in energy storage; d) cloud computing; e) exabyte computing to process "big data"; f) major advances in the health science of aging and bio-engineering; g) genetically engineered high performance crops; h) high-rise urban farming; i) distributed solar power; j)

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[99] For a discussion of this type of strategy see Robert A. Manning, *Envisioning 2030: US Strategy for a Post-Western World*, Atlantic Council, 2012.

[100] See Jonathan Masters, "What Are Targeted Killings? Their Present and Future, Explained", *National Journal*, January 9, 2013.

[101] "Large" is defined as a US Army with active personnel strength of approximately 400,000 with a similar sized reserved structure and a USMC of approximately 175,000 active personnel with somewhat less than 50,000 in its reserve structure. Only China and India will likely sustain larger active ground forces although both will be under increasing budgetary strain as the capital intensity of those forces rise substantially.

[102] For a discussion of the challenge presented to current US power projection capabilities by the diffusion of contemporary and future military technology see Paul K. Davis and Peter A. Wilson, *Looming Discontinuities in US Military Strategy and Defense Planning – Colliding RMA's Necessitate a New Strategy*, RAND, OP326, 2011.

[103] A major response option to vulnerability in cyberspace and space by the US military will be to invest in capabilities to fight future near-peer competitors in a low bandwidth operational environment. Such investments may include the procurement of long-endurance UAVs to act as pseudo-satellites to replace elements of the national security space architecture that have been degraded or destroyed. Combat units will have to be trained to operate in a battlefield which has been "dirtied" by computer network attacks, traditional EW, and the use of an array of electromagnetic weapons. For a description of the increasing Executive Branch's emphasis on developing and possibly employing cyberwar capabilities see David E. Sanger and Thom Shanker, "Broad Powers Seen For Obama in Cyberstrikes", *New York Times*, February 3, 2013.

breakthroughs in water purification through nano-technology; k) driverless ground and air vehicles: and l) globally ubiquitous sensors.

Since this a “surprise free” scenario, an examination of potential shocks and discontinuities aka “black swan” events were explored elsewhere in the previous four and more dire scenarios.

Impact on the Small Arms Ecosystem

The emergence of the next generation of small arms will be driven by a combination of new demand signals both externally and internally. In turn, further innovation will emerge due to major advances if not breakthroughs in science and technology.

In the context of this Hybrid scenario, the most powerful demand signal for further innovation will likely come from the ground forces community to gain and maintain overmatch at the squad and platoon level during counterterrorism and rapid expeditionary operations where higher echelon supporting fires are not immediately available. The most significant military innovation will be the development of an increasingly symbiotic relation between human combat infantry and SOF forces and their robotic helpers whether on the ground and in the air. On the other hand, limits to US defense budgets will place all R&D investment and procurement portfolios under intense scrutiny. It is quite possible that within the ground force community the priority given to small arms is modest if only in the belief that the systems developed and deployed during the early years of the 21st century are “good enough” and that priority should be place on weapon systems and enablers that operate at echelons well above the squad and platoon level.

Appendix C: Ideation Workshop- Objectives and Methods

Network Building

The core leadership team of the Small Arms Science and Technology Concepts effort consisted of personnel from ASA(ALT), NSRDEC, and USMA. Each of the members of this team possessed a broad network of contacts across a variety of domains and communities relevant to the project including research, science, academics, current operations, acquisition, intelligence, engineering, training, doctrine, history, program management, industry, special operations, marksmanship, science fiction, and systems integration.

For instance, USMA's Network Science Center maintains a database of approximately one thousand contacts with interest in the center's work. Individual subject matter experts were selected from this and other databases that had potential for valuable contributions to the small arms effort. "Save the Date" messages and formal invitations followed in an effort to bring a diverse and talented pool of people together to establish the history and state-of-the-art of small arms, to identify small arms capability gaps, to build a set of alternate futures, and to develop and rank small arms future concepts.

Seminar Series

The leadership team selected West Point as the site for a series of five seminars designed to bring together select subject matter experts to tackle the "futurecasting" and "concepting" effort to support the US Army's comprehensive strategy for small arms. West Point offers a beautiful, historic locale with links to academics, research, military leaders (cadets through senior officers), and a crucible for creative thought.

The seminar series consisted of these five events:

- Seminar 1: September 11-13, 2012
  - **Historical Perspectives on Evolutions and Revolutions in Small Arms Technology in the US Army**
  - Discussions on Small Arms Dominance, Lessons from the Past, Evolutions and Revolutions, and Driving Forces.
  - Included facilitated small group break-out sessions to develop insights.
  - Included historical tours of West Point and the small arms wing of its museum.
- Seminar 2: September 27, 2012
  - **Battalion and Brigade Commanders: How Small Arms Capabilities Shape My Decisions.**
  - Focused on criteria to measure small arms effectiveness, desired small arms capabilities, perceptions of currently fielded small arms by US Soldiers, and driving forces/deep trends that will have a major influence on small arms over the next 30 years.
  - Format was an interview-style session with four current active duty operational leaders, some of whom participated via VTC.
- Seminar 3: October 9-11, 2012
  - **FutureCasting 1 - Company, Platoon, and Squad Small Arms Operations**
  - Included facilitated small group break-out sessions to develop insights.
  - Reviewed historical evolutions and revolutions of small arms.
  - Discussions on small arms capability gaps, unit-level requirements, "Black Swan" events and their impact on future warfare, and small arms driving forces/deep trends.
  - Included a historical tour of West Point and a hands-on session with the West Point Simulation Center's Engagement Skills Trainer.
- Seminar 4: November 28-30, 2012

- **Envisioning the "Deep Future" of Small Arms Technology in 2020-2040 (Unclassified)**
- Included facilitated small group break-out sessions to develop insights.
- Focused on the development of alternate futures and the ideation and ranking of future small arms concepts in an Unclassified setting.
- Included a presentation via VTC from ASA(ALT)'s Assistant Deputy for Acquisition and Systems Management.
- Included the participation of science fiction writers from the SIGMA Group.
- Included a hands-on session with the West Point Simulation Center's Engagement Skills Trainer.

o Seminar 5: December 4-6, 2012

- **Envisioning the "Deep Future" of Small Arms Technology in 2020-2040 (Classified)**
- Focused on the development of alternate futures and the ideation and ranking of future small arms concepts in a Classified setting.
- Included facilitated small group break-out sessions to develop insights.
- Discussed barriers to innovation in small arms.
- Developed a snapshot of the emerging analytics associated with the overall effort.

A formal checklist was developed to assist seminar planners with the administrative tasks associated with hosting this and similar technology ideation efforts. Tasks range from web-based registration site management to facilities planning to data capture and sharing.

Ideation Workshop Methods

Seminars 4 and 5 followed an ideation method based on techniques developed at NSRDEC. The objective of this pair of exercises was to convene subject matter experts in small arms technology, military operations, and related disciplines to generate a set of future concepts for small arms systems that could be feasible in the 2022-2042 time frame. Leveraging the network built over the first three small arms seminars a slate of participants was recruited that represented all key stakeholders in the Army small arms community. In addition, Seminar 4 involved participation by a group of science fiction authors from the SIGMA Forum, which offers futurism consulting to the United States government and appropriate NGOs. Faculty from the USMA Department of History facilitated both ideation workshops. Tables B-1 and B-2 in Appendix F list the participants in Seminars 4 and 5, respectively. The Marine Corps (MCCDC and MCWL), ONR, and DARPA were invited to send participants to the ideation seminars, but were unable to do so due to scheduling conflicts.

Seminar 4 opened with a series of briefings on the objectives of this small arms futures study and the workshop methods. Participants were also briefed on a set of *alternate futures* that were developed for the exercise based on the data generated during Seminars 1-3 and additional background research. These futures portrayed four

potential courses along which the strategic environment could evolve over the next 30 years. Participants used the futures to shape their ideas about future small arms concepts. In addition to this briefing all participants received a written version of the four future scenarios – this material is reproduced in its entirety in section X of this report along with a description of the method used in their creation. At the conclusion of the opening briefings the seminar participants were divided into four groups, each led by a facilitator from the West Point Department of History. The groups were carefully constructed to include a diverse range of technical and tactical backgrounds. Participants spent the remainder of the first day of the seminar meeting their group members and having preliminary discussions about small arms technology, their visions of the future, and the alternate futures that had been generated for the seminar.

The majority of the second day of the seminar was spent in the small group setting generating ideas for future small arms technologies in the 2022-2042 time frame. Consistent with best practices for ideation each group was given broad latitude to establish its own dynamic and approach to meeting its assigned task. The task was the same for all four groups: To generate five or more innovative concepts for future small arms that could be matured to Technology Readiness Level (TRL) 6 at some point in the years 2022 to 2042. A TRL of 6 corresponds to a "representative model or prototype system" that has been tested in a "relevant environment" such as a "high-fidelity laboratory environment or in a simulated operational environment" (ASD(R&E), 2011). NSRDEC has found that providing a target TRL during ideation exercises helps bound the concept generation problem and calibrate participants' understanding of the kind of concepts that should be considered. A notional TRL 6 strikes an effective balance between providing a bit of restraint on entirely unfeasible ideas and constraints on creativity driven by the acquisition process.

In generating the concepts, participants were instructed to discuss how their ideas would "play out" in each of the four alternate futures briefed at the outset of the seminar and detailed in a written seminar packet. These futures provided narratives that sketched four hypotheses on the security environment the Army might face and the budgetary pressures affecting S&T. The futures ranged from "hot" scenarios built around direct confrontation between the US and near-peer competitors to a world in which the US has pulled back from overseas commitments in the face of rising domestic challenges. Participants were encouraged to use the futures as inspiration and a source of grounding, not as straight jackets designed to constrict creativity. As they worked through their ideas they were asked to consider whether there are concepts for small arms that are highly optimized for certain future conditions (but less suitable for others) versus concepts that had utility across a range of potential future environments. This technique of using several alternate futures to inform and guide innovation activities has been used successfully by NSRDEC for other problem domains and is widely used in the scenario planning approach to strategy development as described by Schwartz (1996).

Each group was provided with a laptop computer and PowerPoint template for capturing concepts that they wished to submit (shown in Figure C-1). The template included data fields for 1) a description of the technology, 2) the envisioned concept of operation for employing the technology in a tactical setting, 3) a description of how the technology might evolve from current S&T activities, 4) technical barriers that would have to be resolved to get to TRL 6, 5) "other" barriers to developing the technology (which could include political, ethical, legal, bureaucratic, or other issues), and 6) estimates of when the technology would mature to TRL 6 under each of the four alternate futures (which presented different DoD budget scenarios and investment priorities). If participants felt that a particular concept would not be viable under a given future they were instructed to leave the corresponding entry blank. In addition to these fields, participants were asked to name each concept and place it within a taxonomy developed by the Army G3, which decomposes the small arms space into five components: Soldier, Weapon, Enablers (e.g., optics), Ammunition, and Training. A group of roving moderators observed the work of all four groups to ensure that a common level of fidelity was reached in documenting the concepts via this template. Each group was asked to select five concepts to send forward for briefing and evaluation on the final day of the seminar.

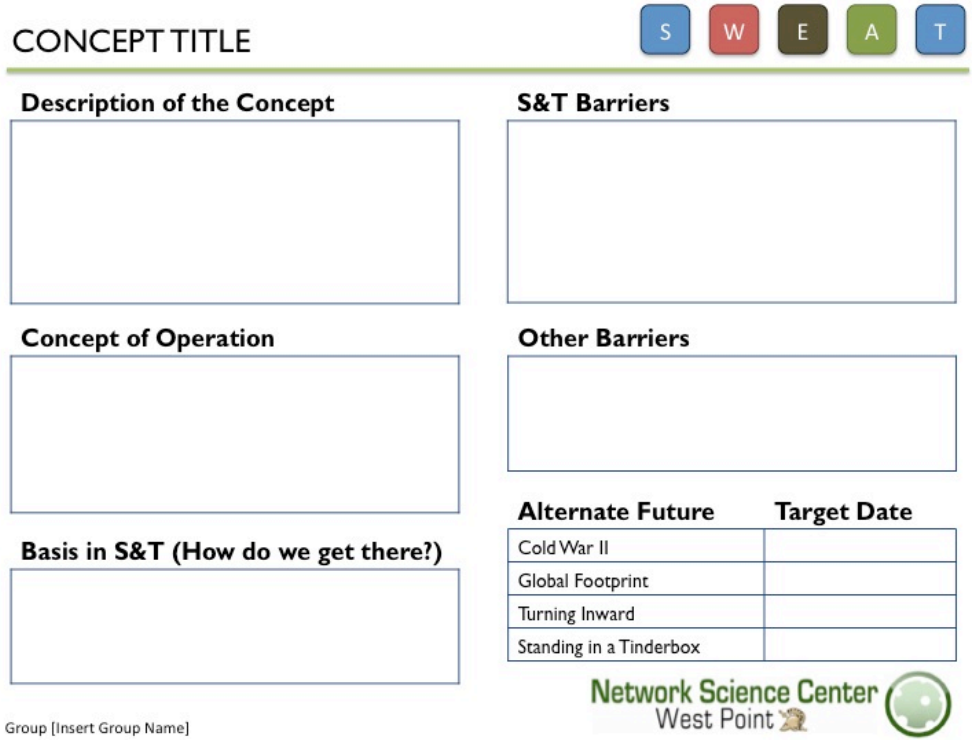

Figure C-1: The template used by participants in the first ideation workshop to capture concept data.

At the end of the second day of the seminar participants reconvened in a plenary session to define a set of criteria by which they could judge the value of the concepts that had been generated. Through an open discussion facilitated by moderators from NSRDEC and ASA(ALT) four criteria were crafted:

> **Anticipated reward.** What is the potential gain in capability that this concept would allow? Is there a "wow" factor in terms of what this concept would let Soldiers and squads do, or how it might influence potential future adversaries
>
> **Anticipated risk.** What is the number and magnitude of technical risk associated with this concept?
>
> **Ripple effects.** Would this concept require major institutional change in investments, doctrine, organization, training, leadership, personnel, the industrial base, society, etc.?

Payoff for other technology domains. Would investments in developing this technology yield advances that would benefit R&D in other important technology domains?

Over-night the seminar facilitation team inserted the participant-defined criteria into a rating form that was distributed to participants on the third and final day of the seminar. After listening to out briefs of all the concepts that were generated across the four groups, each participant completed the rating form. The first item on the form asked participants to prioritize the four criteria using a 0 to 100 scale, with the criterion each felt was most important receiving a "score" of 100, and the remaining criteria scored relative to that benchmark. Each participant then scored the 20 concepts that had been presented on each of the four criteria. This was done by first selecting the concepts that were deemed best and worst based for a given criterion. Participants entered these concepts onto the rating form to anchor two ends of an analog rating scale. Each participant then scored the remaining concepts relative to the best and worst concepts by placing marks on the scale relative to the two anchor points. This process was repeated for all four criteria such that all 20 concepts were scored on all criteria. The criteria prioritization and concept scores were used to create a weighted value model as described below. The seminar ended with a closing round of discussion that followed the rating task.

The following week another seminar was held to further analyze the concepts that emerged from the first ideation exercise. The participants in this seminar (Table B-2) consisted of several experts that had attended the first seminar along with some new individuals. This seminar had two objectives. First, a classified work environment was established to allow participant to share information about small arms technologies and threat data up to the Secret level. This capability was provided based on feedback from prior seminars in which attendees indicated an interest in sharing classified information. As it happened, no classified information was shared at this seminar. The second objective of the seminar was to consider in greater depth the strengths and weaknesses of the concepts that had been developed the week prior within the context of the four alternate futures. While participants in the first ideation workshop discussed the applicability of their concepts to the futures there was insufficient time to do a deep dive into this issue in that session.

The second ideation seminar opened with a round of introductory briefings on the seminar objectives and methods. The alternate futures were also briefed and participants were provided the same detailed packet that had been used during the first exercise. Participants then broke out into two small groups comprised of technical and tactical experts. Each group was assigned the task of reviewing ten of the concepts that had been generated the previous week. An effort was made to ensure that the groups had representatives of the teams that had generated the assigned concepts to provide background and insight into the concepts. The groups discussed the applicability of each concept for the four alternate futures and completed a template to record their conclusions. This template, which is shown in Figure C-2, had a data field for "strengths" and "weaknesses" of a given concept for each of the four futures. The definition of what might constitute a "strength" or "weakness" was defined for the participants by the seminar facilitators to include both political, strategic, and cultural issues; doctrinal, organizational, training, leadership, personnel, logistical, or other operational issues; and technical issues. The groups also provided a summary consensus rating of the applicability of each concept for each future using a seven-point scale. The groups briefed their findings on the final day of the three-day seminar, which ended with a final open discussion.

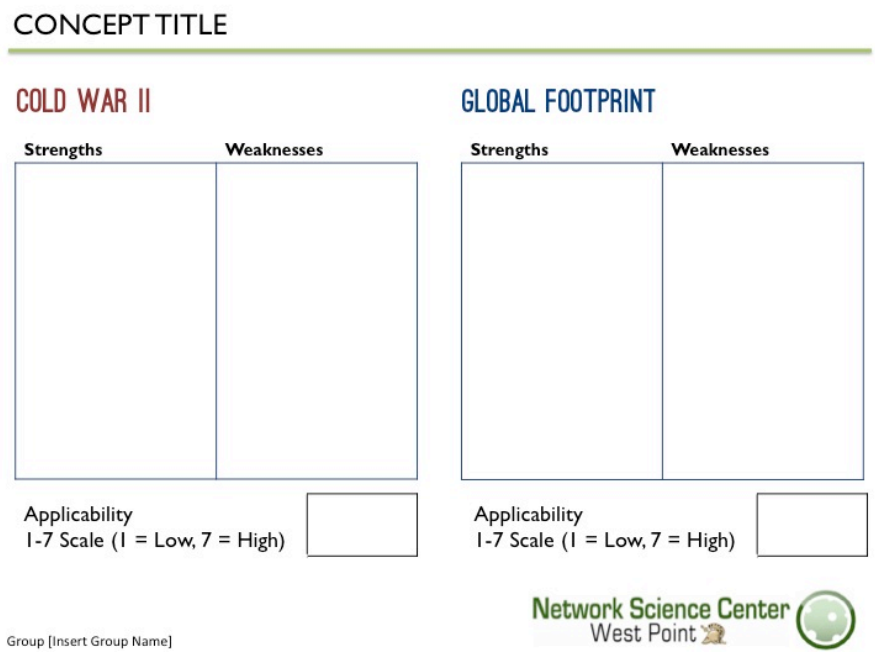

Figure C-2: Template used to capture data at the second ideation workshop.

Appendix D: New Concepts for S&T Exploration

Small Arms Concepts: 2022-2042

Concepts developed at the seminar series addressed the five SWEAT components: Soldier, Weapon, Ammunition, Enablers, and Training. Participants in Seminars 4 and 5 rated the utility of developed concepts using a multiple attribute utility model with four criteria:

- Benefit for Soldiers/squad in terms of mission capability.
- Technical risk.
- Consequences/ side effects across DOTMLPF.
- Potential to drive S&T that can benefit other technology domains.

The concepts generated during the ideation exercise are provided in the following table:

CONCEPT NAME	CONCEPT DESCRIPTION
Micro Robotics	Miniaturized robotic weapons mounted on insect / bird sized robots, controlled remotely through cameras. Able to gather intelligence – reduces collateral damage.
Effects Options	A family of munitions that delivers multiple types of effects on enemy Soldiers or Equipment (e.g., cyber attack round, disruption of the human system, etc.); Munitions are variable – delivery system can be tailored depending on the situation.
Energy Harvesting Concept	Rounds – As they are fired, harvest energy from flight that powers on-board guidance, sensors, etc. Weapons – Harvest recoil energy for electrical power to supply fire control systems, sights, etc.
Robotics Support	Develop robots that can carry equipment for the Soldier – lead into a room, check mine fields, mount mortars, or medium / heavy machine guns.
Neuroscience Enhancement	Brain control of the weapon; embedded neuro-training effects.
Weapon Informatics Soldier-Human (WISH)	Weapon informatics that integrates signals of Soldier's vitals, equipment, location, and targeting. Power provided by battery and weight of equipment leveraged to balance that. Networked into other local members of small unit to allow immediate feedback on status. Self-configurable for the local conditions.
Genius Ammunition Project (GAP)	Ammunition that is capable of altering its own capabilities based on user command, including a range such as armor piercing, standard, high-velocity, low velocity, and non-lethal. This would be accomplished by used signals transmitted through the weapon. This also includes a failsafe on IFF codes (perhaps through the WISH project). Steerable capability- micro-adjustments in flight. Possible innovative readouts for in-flight sensors (radial readout)
Soldier Asymmetric Vision Equipment (SAVE)	Soldier deployed spectrally tunable obscurants with commensurate sensors, optics, and optics that allow users to see one another while non-users are denied vision. Can also create localized communications baffling for targets, denying radio/phone contact.

CONCEPT NAME	CONCEPT DESCRIPTION
Squad Level Active Collaborating Knowledge (SLACK)	A collaborative weapon system that is networked to allow the maximum firing effect from a squad, de-conflicting targets, prioritizing threats, and directing the firepower and collective maneuvering of the small unit.
Directed Energy Negation and Integration (DENI)	Multirole laser device that offers targeting data, target detection, communications, and degradation of opponents' optical sensors. Added capabilities for illumination and 3D imaging of battlefield. Temporary incapacitation of opponent's vision.
WASP (Weaponized Assault Surveillance Platform)	Remote drones (insect sized and smaller), using Micro Electro-Mechanical System (MEMS) technology, would identify / locate targets and deliver a flexible effect. Think semi-autonomous reconnaissance/lethal UAVs at an insect scale.
Avatar (Advanced Virtual Autonomous Tethered Assault Robot)	A personally controlled battle surrogate that can be deployed globally and fully immersed into the combat environment. Think an android Soldier.
Electric Rifle	An adaptable, scalable, and tunable personal weapon system that uses stored electrical energy to deliver effects spanning from nonlethal to lethal. The weapon would incorporate an electromagnetic (EM) kinetic energy (KE) launcher and a broad spectrum directed energy (DE) source in order to bring threats to a desired endstate.
HEPA (Hyper Energy and Power Ammunition)	Materials that have order of magnitude increases in energy storage and power delivery that enable revolutionary changes in how we shape the battlefield. Think Disruptive Energetics
CLAWS (Combat Lightweight Automatic Weapon System)	System of systems lightweight weapon (incorporating a weapon, fire control unit and lightweight ammunition) that provides full effects over the entire range of use.
IQ Box (Soldier Assistant)	Can access, observe, assess, compute wide variety of information. IQ Boxes communicate with each other without command. Direct neural interface with micro-computer on helmet. Live situational awareness. Computer can see what Soldier sees. Mentally controlled filters. Gathers information as well from external sensors and squad network. Digitally assisted telepathy
Kinetic Modular Weapon Platform	Looks similar to basic infantry weapon, but round is separate from propellant. Allows Soldier to tailor round/propellant combinations to achieve a range of lethal and nonlethal effects, rate of fire, etc.
Self-Healing Weapons	Weapon self-cleans / identifies / mitigates / notifies weapon wear Optimizes accuracy to environment
Frontline Solid Fabricator	A "3D printer" carried by the squad. Soldiers insert a variety of locally scavenged materials (e.g., scrap metal), output is emergency SARP, bullets, and other essential consumables.
Dirty Jobs ("Mike") Rowe-bot	Acts as assistant gunner; Bipedal / humanoid; Moves autonomously and intelligently; Engages targets under direct direction; Integrates with IQ box; Enhanced hearing/sight/acoustic sensing

The following additional concepts were generated by cadets at the United States Military Academy during a separate ideation exercise:

CONCEPT NAME	CONCEPT DESCRIPTION
MAPS (Military Artificial Proxy Soldiers)	Robotic Soldier that would take the place of organic troops in high-lethality areas. It would generally be humanoid in form (with some smaller animal forms for specialized tasks) and capable of using current military hardware. MAPS would, as a result, constitute a form of drone Soldier with limited artificial intelligence supplemented by extensive remote human direction.
HOPE (Hyperbolic Operations Projector-Experimental)	Thermobaric shockwave projector attuned to the frequency of soft tissue rupture. This technology would allow for a bypassing of armor while still creating lethal effects in the targeted individual. HOPE would most likely take the form of a large, crew-served small arm using matched thermobaric ammunition. While obviously causing stress to the weapon itself, the effect would be far in excess of the wear to the weapon. It would employ a simple form of ammunition with a chemical charge in the propellant that would generate the shockwave itself.
HERO (Holographic Environment Radius Operations)	Invisible Soldiers concept accomplished through a variety of techniques, including a combination of adaptive camouflage, alterable reflectivity, active projection, and quantum electronic cues. HERO would be deployed as a suite of hardware distributed across the Soldier in combination with a laser rangefinder. This would enable either concealment at a distance or displacement of one's image when in a kinetic environment.
PREP (Personal Rocket Explosives Project)	Pistol or SMG size rocket launcher that can be shot from one's hand rather than the shoulder. PREP would have both an adjustable velocity and a lower recoil than the shoulder-mounted rocket launcher. It would have the ability to employ various loads from chemical and biological to explosive and shaped charge, while there would be room for a possible evolution to wire or laser guidance.
Super Soldier (Bioenhancement)	Biomechatronically-enhanced Soldier that has improved strength, reflexes, senses, and survivability that are amenable to onsite task and/or condition specific enhancement. During development individuals would be recruited and converted into superhuman Soldiers with the explicit goals of enhancing battlefield performance.
Exoskeleton (Iron Man)	Integrated weapons system encasing the warfighter in a mission performance enhancing suit that enhances weapons use, communications, and loadbearing. The concept relies on accomplishments in robotics, materials development, sensors, software, networking, and interface development.
FAKE (Flabbergasting Armament Kinetic Employer)	Seeks to prompt the economic exhaustion of an opponent by seeming to progress toward an exotic weapon system and triggering an expensive and futile effort by the peer opponent. Notionally, FAKE would be a solar-powered guided weapon capable of defeating armor and having a personnel and electronics kill capacity. In fact, FAKE would exert its effect by spurring a peer opponent to waste R&D resources.

Table D-1: Future Small Arms Concepts and Descriptions

SWEAT Analysis

As described above, the Army G3 has established a model for characterizing the small arms space comprised of five factors – Soldier, Weapon, Enablers, Ammunition, and Training (SWEAT). The concepts generated at the first ideation workshop were categorized according to the SWEAT model as a way of characterizing how they fit into the overall picture of the Army's small arms strategy. The rubric for categorizing a concept was straightforward for all of the categories with the exception of Soldier. Concepts were linked with the Weapon, Enabler, Ammunition, and/or Training factors if they directly addressed an innovation in one or more of these domains. A decision was made to count a concept as linked with the Soldier factor if it either would affect the role of the Soldier on the battlefield or significantly change the interface between the Soldier and his small arms system. Many of the concepts were in fact systems and could link to multiple SWEAT components. The most evident finding is that most of the concepts had some link to weapon enablers. In contrast, only three concepts had direct implications for training. The dearth of training-related concepts is also apparent in similar futures studies done by JSSAP. Many of the concepts would drive a fundamental reconsideration of the relationship among the SWEAT factors. In particular, several of the concepts had to do with directed energy weapons that would require a very different notion of "ammunition". Similarly, there were multiple concepts for offloading the small arms system from the Soldier to a robotic platform. Removing the constraints imposed by engineering a man-portable weapon would significantly affect the trade space relating the Soldier, his weapon, and attached enablers (i.e., traditional optics are no longer needed). While participants agreed that the SWEAT model worked well enough as a taxonomy for future concepts, it appears that consideration should be given to the possibility that the factor definitions could look quite different in the future.

Concept Clusters

In looking across the concepts generated by the work groups there were four broad technological themes that emerged. Several of the concepts spoke to the notion that future small arms technologies must provide tailorable effects that increase the scope of the "playbook" at the tactical level of war. This would include options for organic coordination of direct and indirect or counterdefilade fires over a range of distances as well as the ability to shift seamlessly between lethal and nonlethal effects. At issue is the squad's ability to adapt to its circumstances in the moment, as opposed to locking in its small arms options before the mission begins. There was a great deal of discussion about the "arms room concept" for regular Army platoons and squads. The idea was that units would have access to modular weapon and ammunition components that could be selectively combined to build a small arms suite designed for a given set of METT-TC conditions. The future concepts generated at the workshop went a step further – the arms room concept assumes that the platoon or squad would have to work with whatever systems it assembled prior to leaving the line of departure. The tailorable concepts contributed by the workshop

participants would enable Soldiers and small units to adapt their application of force on the fly, offering a presumably greater degree of flexibility.

Another theme that emerged from the concepts is the idea that future small arms will feature a much greater degree of synergy with the Soldier. In place of the cheek weld several of the concepts (e.g., WISH and IQ Box) suggested that the Soldier-weapon interface would involve a more intimate connection facilitated by brain-computer interfaces or natural language interfaces. Other concepts (e.g., SLACK) called for networking of fire control and battlefield data to improve the coordinated effects that could be achieved by squads. The workshop participants were confident that interfaces in which the weapon responds directly to the intention of the Soldier, in effect making the weapon a "smart" partner as opposed to passive instrument, are well within reach. This suggests we are nearing a tipping point in the design of small arms that will create new possibilities for control of the weapon that could lead to more precise delivery of effects scaled to the tactical situation.

A third theme was the profound way that robotics, whether semi- or fully-autonomous, could reshape the nature of small arms and their relationship to the Soldier. This is well-tread ground in science fiction and, with the rise of sophisticated drones and squad-level ground robots, an increasingly normal part of modern military operations. In a sense, robotics can be seen as another expression of a new paradigm in Soldier-weapon interfaces. None of the participants in the workshop foresaw a scenario in which fully autonomous robots would make the decision to fire on a human target. This "Terminator" view of ground military robotics goes against established legal and moral strictures that are unlikely to change over the next 30 years. However, offloading the effects delivery components of the small arm while maintaining human control over fire control affords radical innovations in how we develop small arms. We will revisit the transformative effect of ground robotics as a small arms platform later in this report.

Finally, several of the concept hinted at ways that future small arms could reduce the logistical tail of the squad by lengthening the life span of weapon parts through self-healing nano-materials, to enabling Soldiers to print replacement parts for their weapons in the field. The concept of energy harvesting from the kinetic energy unleashed during weapon fire was also discussed as a way of offsetting the total power requirement of future electronics. While logistics concerns are not a part of the SWEAT model they are integral to evaluating the role of small arms as part of the overall conduct of military operations.

Utility Ratings

As discussed above, at the end of the ideation workshop participants completed a survey that produced quantitative ratings of the concepts on four criteria: anticipated reward, anticipated risk, ripple effects, and payoff for other technology domains. A utility model was developed for each participant that calculated the value of a given concept as a weighted sum of the criteria scores the participant assigned the concept, with the weights determined by the priority ratings assigned to the four criteria. The scores and weights were scaled to produce a value scale ranging from 0 to 100. The criteria weights were distributed sensibly, with benefit for Soldiers/squads receiving the highest weight, technical risk and payoff for other technology domains weighted approximately equally, and risk of ripple effects with consequences for other DOTMLPF domains of least concern for these participants (Figure 2). Figure 3 shows the aggregate values of the concepts averaged over participants with the concepts grouped according the four emergent themes discussed above. It is evident that while the utility values varied three concepts emerged with particularly high ratings: CLAWS, the IQ Box, and Micro-Robotics. The concept with the lowest overall utility was the Frontline Solid Fabricator.

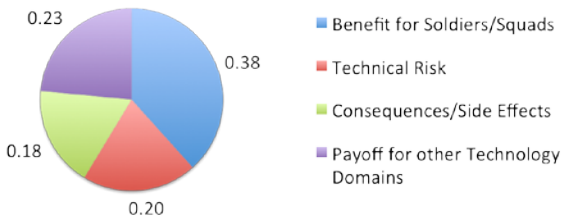

Figure D-1: Criteria Weights

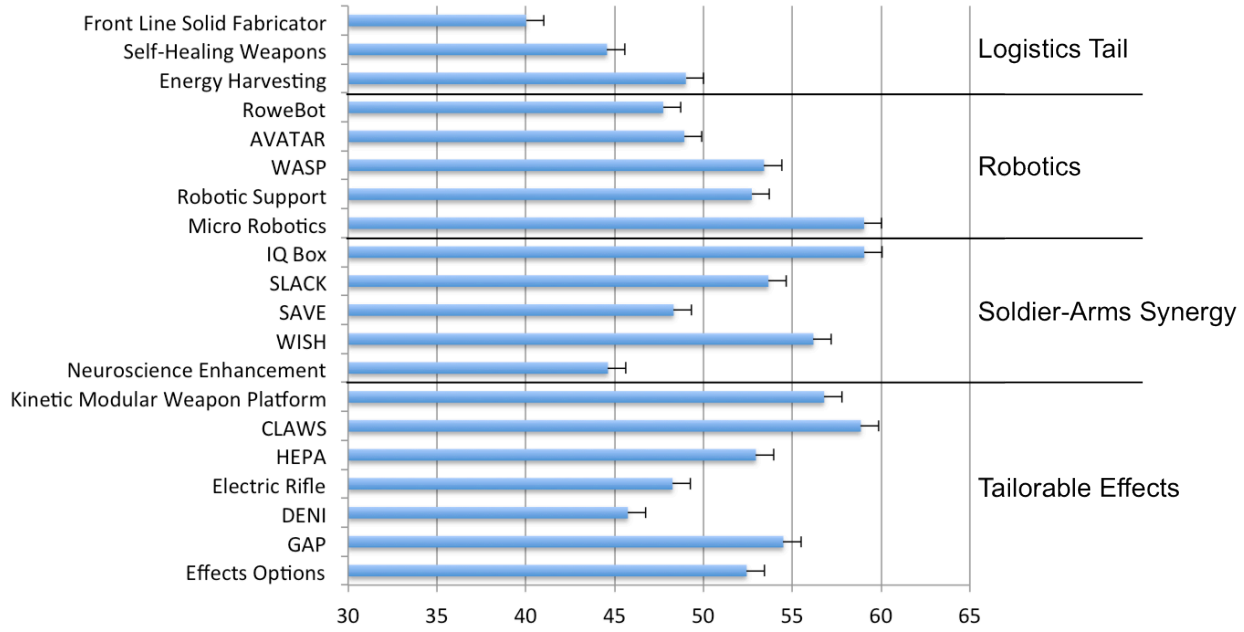

Figure D-2: Aggregate utility values of the concepts averaged over participants

Applicability Across Alternate Futures

During the second ideation workshop participants provided a rating of how applicable each concept would be for each of the four alternate futures. The results are shown in Figure 4. The most striking finding is that none of the concepts provided an applicable capability across all of the futures. In particular, very few concepts were deemed useful in the Turning Inward scenario. In fact, the CLAWS concept, which received a high overall utility rating during the first workshop, received poor marks in its applicability to this alternate future. The trade-space defined by the utility scores from the first ideation seminar and the applicability ratings from the second seminar is depicted in Figure 5. The lines shown in the Figure 5 demark the median scores or utility and applicability and divide the concepts into four "bins" – those with relatively high utility and high applicability, those with high utility but low applicability, those with low utility but high applicability, and those with low values on both dimensions. This data could be used to shape an understanding of ripe targets for S&T investment.

	Cold War II	Global Footprint	Turning Inward	Standing in a Tinderbox
Effects Options	2.50	1.00	-1.00	3.00
GAP	1.56	0.00	-1.00	2.80
DENI	1.50	1.00	0.50	2.00
Electric Rifle	1.00	2.00	2.00	2.00
HEPA	2.00	2.00	0.00	2.00
CLAWS	2.00	2.00	-2.00	3.00
Kinetic Modular Weapon Platform	2.00	2.00	-2.00	3.00
Neuroscience Enhancement	2.00	3.00	0.50	2.50
WISH	1.80	2.00	0.00	3.00
SAVE	0.50	1.50	-1.50	1.00
SLACK	0.00	0.50	-1.00	0.00
IQ Box	2.00	2.00	2.00	2.00
Micro Robotics	2.00	1.00	-0.50	2.50
Robotic Support	1.50	2.00	-2.00	2.00
WASP	2.00	2.00	2.00	2.00
AVATAR	1.00	-1.00	-2.00	3.00
RoweBot	1.00	1.00	0.00	2.00
Energy Harvesting	2.00	2.25	2.00	3.00
Self-Healing Weapons	2.00	2.00	-1.00	3.00
Front Line Solid Fabricator	-1.00	1.00	0.00	1.00

Figure D-3: Concept applicability across Alternate Futures

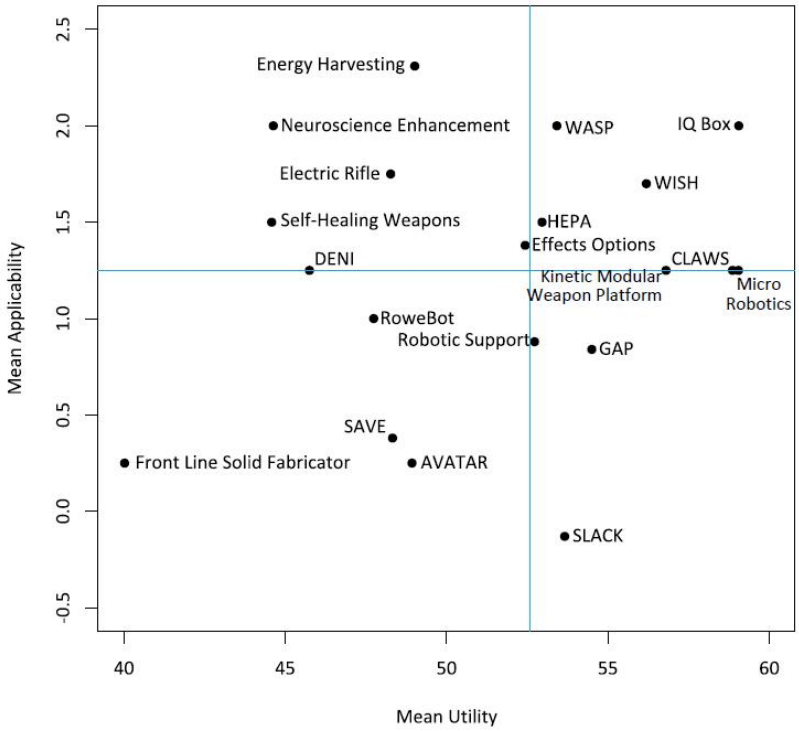

Figure D-4: Tradespace defined by the utility scores from the first ideation seminar and the applicability ratings from the second seminar

Any disconnects between the utility scores generated from the first workshop and the applicability ratings from the second workshop might be attributable to the different dynamics that were in force during the two exercises. The first ideation workshop was fairly "positive" in tone, both by virtue of the instructions given to the participants and the type of individual who attended. This workshop, and the utility ratings that emerged, was biased towards an overall optimism about technology. Although participants were instructed to think about the applicability of their concepts across the futures, few groups did so, electing to generate ideas that were innovative and interesting from a technical standpoint. In contrast, at the second workshop participants were asked to focus in on deep consideration of the applicability of the concepts across the futures. This critical lens, coupled with the personalities of those who attended the meeting, led to a somewhat more skeptical view of how the capability the concepts would provide across distinct future conditions. This speaks to the value during ideation work of bringing in multiple points of view, to include "technophiles" and those with more pragmatic views of the limits of technology. It also points to the importance of designing the ideation exercise to specifically adopt a critical eye to ensure that the ideas that emerge are understood in their full context.

Appendix E: Network Analysis

Background

As a part of the Small Arms Futures project, the Network Science Center at West Point also experimented with an innovative application of traditional network analysis.

This project presented an opportunity to collect data about the study participants and to develop a methodology that can empower decision makers with information concerning power brokers and influential organizations within specific communities in the Department of Defense Science and Technology (S&T) community.

Based on the initial insights gained as the work progressed, the team also developed an initial Science and Technology network framework that will allow decision makers to accurately understand the linkages and relationships that exist between Science and Technology efforts, identified capability gaps, and Programs of Record. This framework has evolved into an innovative Decision Support Tool (DST). The DST allows decision makers to holistically analyze the entire S&T effort, determine if the priority capability gaps or Programs of Record are actually being addressed in the appropriate fashion, and provides the ability to understand how the network is affected by the cancelation or re-prioritization of a specific program. This initiative will be discussed in greater detail in a later Network Science Center report.

Use of Network Analysis

Network Analysis has been commonly utilized in recent years to analyze terrorist networks or as a targeting tool in combat operations. The Network Science Center is currently involved in several research efforts that are advancing the use of these quantitative techniques and methodologies to address applied social science problems as well as exploring the use of these techniques to assist in the development of decision support tools.

Data Collection

As part of the Small Arms Futures electronic registration process, participants were required to answer a short survey. The survey consisted of some basic demographic information and the gathered the following data:

- Employment Status: Military, Government Civilian, Contractor, Academic, or Commercial Sector
- Current Organization
- Superordinate Organization
- Military Service
- Current Rank or Previous Rank
- Education Level
- Other Organizations currently associated
- Prior Organizations
- Current Supervisor
- Names of People (and that person's organization) that they would reach out to if they required assistance in the following areas:
  - Military Doctrine
  - Technology
  - Military Weapons

Data Analysis

The data that was collected from the seminar participants was initially analyzed with the intent to see if insights gained from this network could potentially be effective in identifying the influential individuals and organizations in the S&T community.

Our initial proof of concept analysis focused on the linkages formed by analyzing people and organizations. By mathematically manipulating this data it is possible to study how people are connected through organizations and how organizations are connected through people. Network science measures such as degree centrality, betweenness centrality, and eigenvector centrality provide insights into the various roles and groups in a network such as which nodes are the connectors, mavens, leaders, bridges, and isolates.

Our initial analysis focused on three commonly used centrality measures:

- Degree centrality-a measure of a node's importance based on the number connections a node has in comparison to the total possible connections in the network.
- Betweenness centrality-a measure of a node's "interpersonal influence." It measures how often a node lies between two other nodes along their geodesic or shortest path.
- Eigenvector centrality-measures a node's importance by examining that node's connectedness to other influential nodes in the network. Being connected to an influential node will increase a node's own influence and therefore its eigenvector centrality.

Initially, we constructed a bipartite affiliation network (Figure D-1). This type of network enables us to analyze linkages between people and organizations participating in the series of seminars.

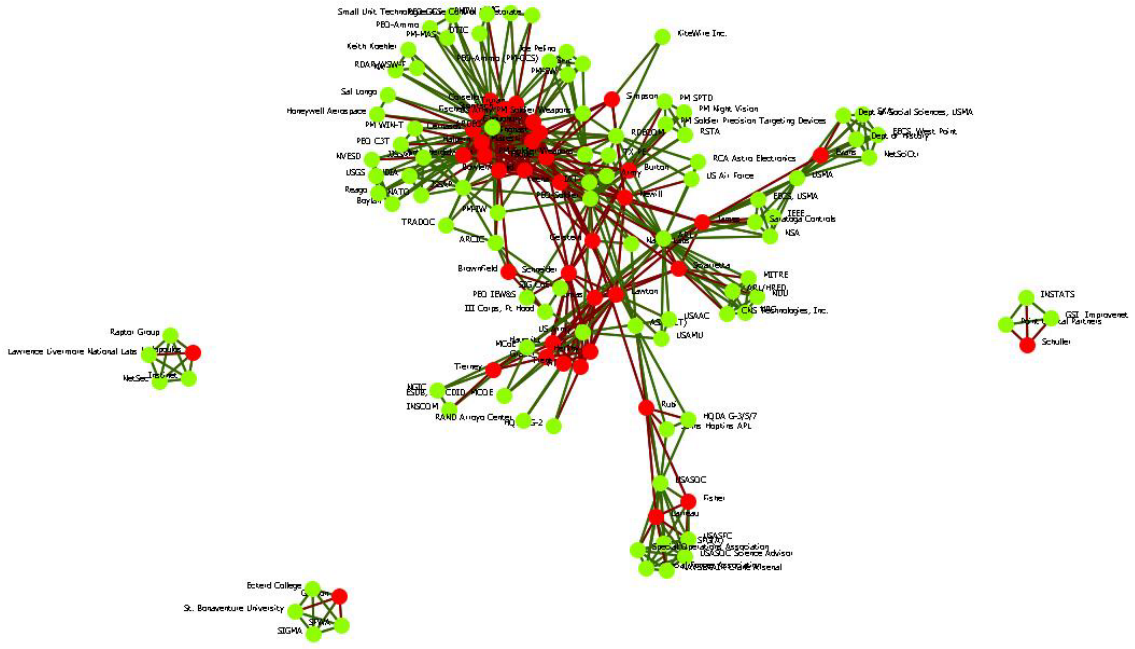

Figure E-1: Bipartite affiliation network of small arms seminar series attendees.

Based on this initial network, we constructed two different single node networks. The first is a network of organizations and illustrates how they are connected through individual ties:

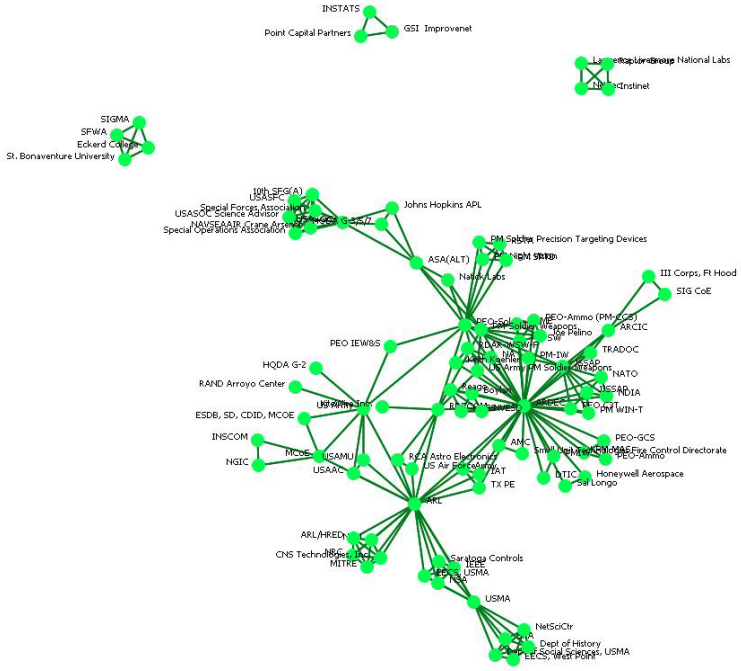

Figure E-2: Single node networks of small arms seminar series attendees.

Based on this analysis, we can now identify influential organizations based on their centrality measures:

	Degree	Betweenness	Eigenvector
Org 3	.398	.459	.311
Org 44	.226	.322	.345
Org 2	.151	.208	.311
Org 35	.065	.154	.091

Table E-1: Influence of seminar series attendee organizations based on centrality measures

Centrality measures are commonly normalized on a scale from zero to one. This convention allows a more effective comparison of nodes within the network. For example, in this network model, Org 2 is approximately twice as central (.151) than Org 35 (.065).

The second is a network of individuals and illustrates how they are connected through shared organizational ties.

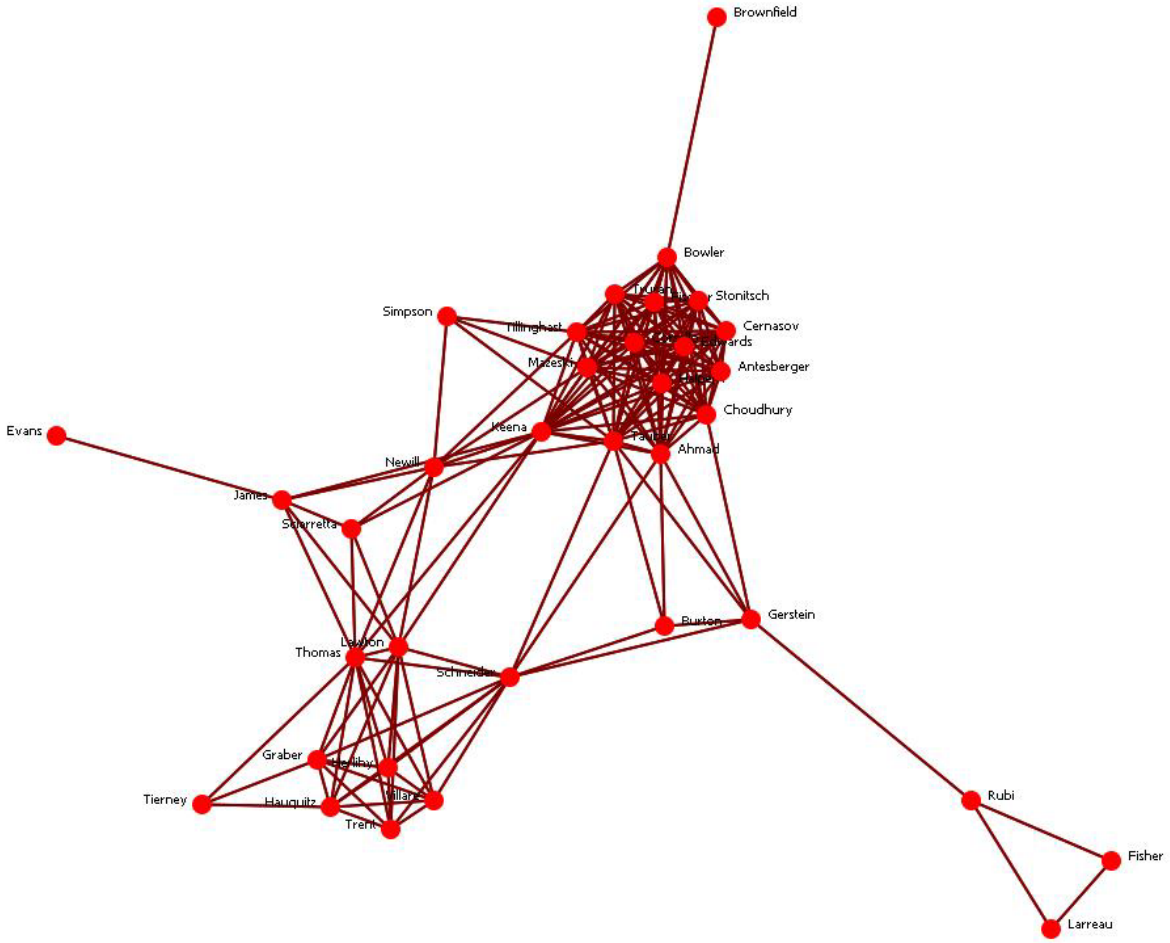

Figure E-3: Network of seminar series attendees connected by shared organizational ties.

Similarly, we can also identify influential individuals based on their centrality measures:

	Degree	Betweenness	Eigenvector
Agent 17	.514	.179	.375
Agent 28	.514	.107	.382
Agent 2	.460	.073	.368
Agent 3	.405	.050	.355
Agent 11	.162	.142	.089
Agent 24	.297	.137	.078

Table E-2: Influence of individual seminar attendees based on centrality measures.

Once again, the values are normalized so in this case, Agent 17 (.514) is approximately three times more "central" than Agent 11 (.162).

In order to attempt to assign characteristics or roles to organizations and individuals the team decided to analyze the relationship between betweenness centrality and eigenvector centrality. These two measures capture different aspects of a node's characteristics and mathematically, there is a significant difference between a node's

ability to connect sub-groups within a network, betweenness centrality, and the node's connectedness to other influential nodes, eigenvector centrality.

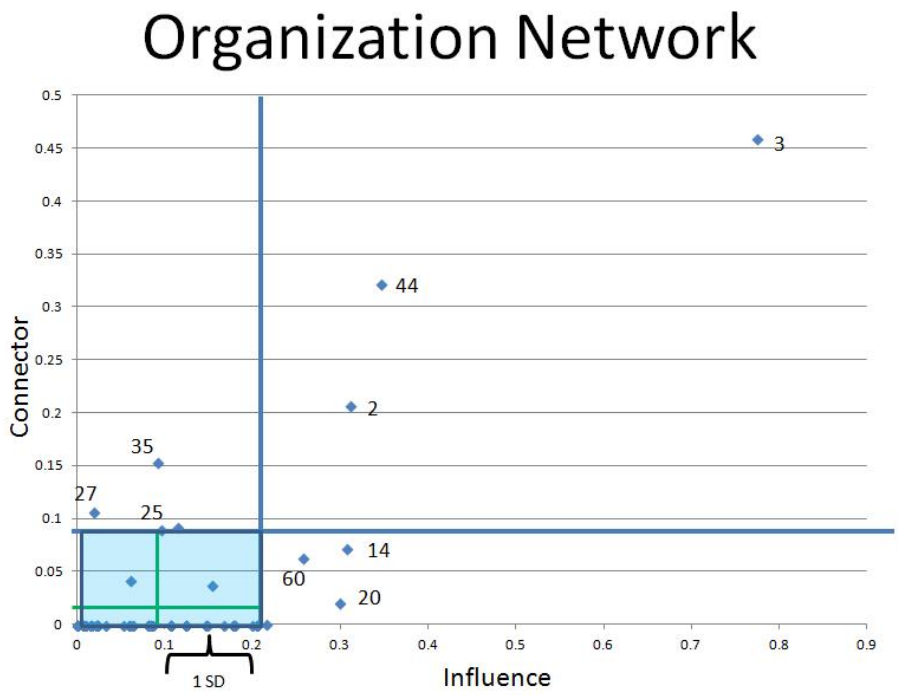

Figure E-4: Organizational network showing the relationship between connector and influence values.

The team determined the mean values of both betweenness centrality and eigenvector centrality for the entire data set. Any node that had a measure that was greater than one standard deviation from the mean value was deemed influential. The shaded area of the graph includes nodes that are not influential and we call them Peripheral Players. Nodes that have a betweenness centrality measure greater than one standard deviation than the mean but their eigenvector centrality is within one standard deviation from the mean are called Gatekeepers (the upper left quadrant of the graph).

Nodes that are have an eigenvector centrality measure greater than one standard deviation than the mean but their betweenness centrality is within one standard deviation from the mean are called Influencers (the lower right quadrant of the graph).

Nodes that have both a betweenness and eigenvector centrality measure greater than one standard deviation above the mean are called Powerbrokers (the upper right quadrant of the graph).

Based on the dataset compiled of the seminar participants, we can see that the Powerbroker organizations are Organizations 2, 3, and 44. The team also constructed a graph that analyzes individuals that participated in the series of seminars:

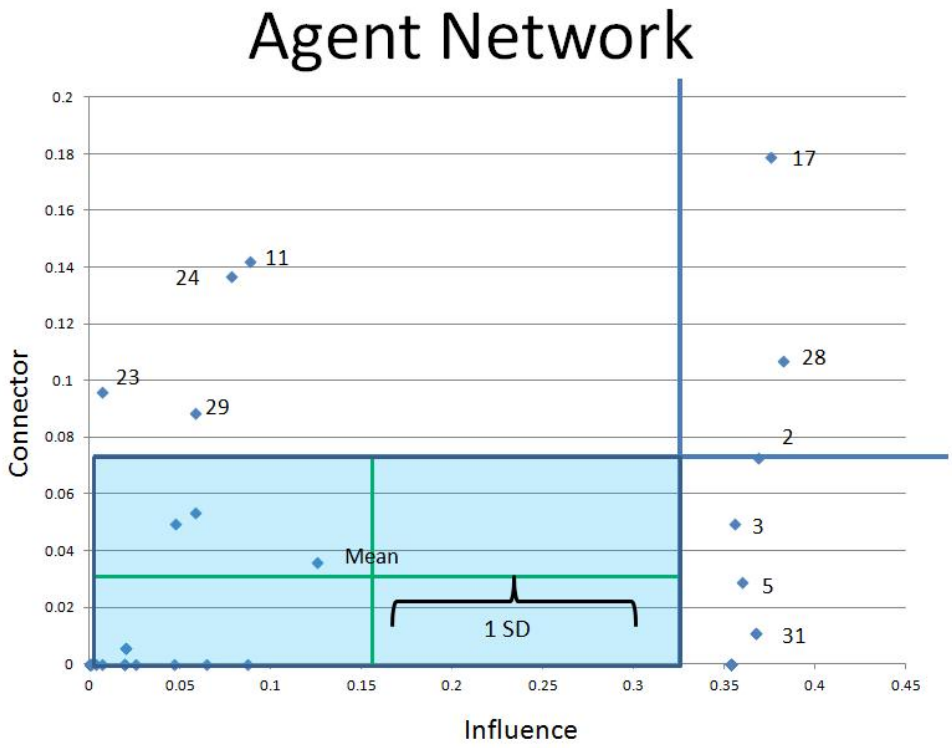

Figure E-5: Agent network showing the relationship between connector and influence values.

The participant survey also requested additional names of subject matter experts who are one degree removed from the seminar participants. This is a common sociology data collections technique know as the "snowball technique." This technique is often used to uncover influencers in populations that are difficult to access. The team has not yet incorporated this additional data into its analysis but this additional analysis has incredible potential.

Way Ahead

This initial analysis yields many powerful insights. It is extremely important to note that it is based solely on the data collected on the participants in this particular series of Small Arms Futures seminars. In order to be effective for decision-making, the data set has to be expanded to capture a much larger portion of the Department of Defense Science and Technology community. Based on the positive results of the proof of concept study, the team plans on expanding the effort in several ways.

First, the team is establishing a community of innovators both inside and outside of the Department of Defense called the Future of Army Science and Technology Network (FASTNet). Anyone can join the group and the hub of the group's activity is a web site that is currently under development. This web site will be a place for anyone interested in military research efforts to "gather" and discuss innovations in science and technology. In order to join the group, the candidate must complete an application, which includes similar data to that collected in the Small Arms Futures project and then be approved by the group moderator. As the group expands, an innovative ranking system will be implemented allowing members to gain stature in the group and assist in the weighting of linkages in our ever-evolving network model.

Second, the team will continue to conduct analysis on the data set allowing us to devise new and innovative grouping algorithms, and techniques for identifying pockets of influence, both positive and negative, and identifying hidden influencers in the network.

Appendix F: Small Arms Seminar Attendees

Name	Title	Organization
LTC Matt Bowler	Branch Chief for Movement and Maneuver	ARCIC
Mr. Fareed Choudhury	Branch Chief Non-Lethal & Scalable Effects	ARDEC
Dr. Joshua Keena	Chief, Special Programs	ARDEC
Mr. William Truran	Engineer	ARDEC
Mr. Clinton Fischer	General Engineer	ARDEC
Mr. Ralph Tillinghast	Lab Director	ARDEC
Mrs. Regina Stonitsch	Small Arms Fire Control Engineer	ARDEC
Mr. Ralph Mazeski	Small Cal Munition Tech. Branch Chief	ARDEC
Dr. Andrei Cernasov	Innovation Associate	ARDEC
Mr. James Newill	Lethality Capability Research Area Manager	ARL
Mr. Nathan Burkholder	Director, Technology Innovation Studies	ASA (ALT)
Ms. Julie Rubi	Requirement Staff Officer, Soldier Weapons	G-3
Mr. Paul Villare	Chief, Foreign Technology Division	HQDA G-2
Mr. Peter Schuller	Managing Director	INSTATS
Mr. John Edwards	Program Management Official	JSSAP
Mr Jere Simpson	President	KiteWire Inc.
Mr. Greg Graber	Capabilities Developer	MCoE
Mr. Aron Hauquitz	Chief, Small Arms Section	MCoE
Dr. Jason Augustyn	Research Psychologist	Natick Labs
Mr. Wayne Antesberger	Soldier Sensors Branch Chief	NVESD
Mr. Chris Schneider	PM SMS	PEO Soldier
Mr. James Burton	Director, Maneuver Systems	PM Soldier Precision Targeting Devices
Mr. Mahmoud Ahmad	Chief, Future Weapons Division	PM-Individual Weapons
Mr. John Corsello	Science & Technology Lead, Small Caliber Ammunition	PM-MAS
Mr. Michael Tauber	Director, Systems Engineering	PM-Soldier Weapons
MAJ Chris Springer	Research Fellow	RAND Arroyo Center
LTC Stoney Trent	Research Fellow	RAND Arroyo Center
Mr. Elias Ladopoulos	Special Projects	Raptor Group
COL Michael Brownfield	Director, Battle Lab	Sig CoE
Dr. Charles Gannon	Science Fiction Writer	SIGMA Forum
Mr. Mark O'Green	Science Fiction Writer	SIGMA Forum
Mr. Tom Purdom	Science Fiction Writer	SIGMA Forum

LTC Bradley Fisher	Chief, Force Modernization	SOCOM
Mr. Troy Lawton	USAMU Ballistics	USAMU
LTC David Siry	Department of History	West Point
Dr. Charles Thomas	Department of History	West Point
COL John Graham	IID	West Point
Mr. John Willis	IID	West Point
Mr. Dan Evans	Network Science Center	West Point
Dr. John James	Network Science Center	West Point

Table F-1: Participants in the first ideation workshop (Seminar 4).

Name	**Organization**
Matt Bowler	ARCIC
James Burton	Product Manager, Soldier Precision Targeting Devices
John Corsello	PM-MAS
John Edwards	JSSAP
Dan Evans	West Point
Clinton Fischer	ARDEC
Bradley Fisher	SOCOM
Michael Harris	USSOCOM Directorate of Science & Technology
George Herc	ARDEC
John James	West Point
Joshua Keena	ARDEC
Victor Krus	Training Brain Operations Center
Kurt McNeely	ARDEC
James Newill	ARL
Patrick O'Connor	ODASA(R&T)
David Phipps	Close Combat TISO
Ty Seidule	West Point
Joseph Snyder	ARDEC
Michael Tauber	US Army, PM Soldier Weapons
Auther Thomas	MCoE
William Truran	ARDEC

Table F-2: Participants in the second ideation workshop (Seminar 5).