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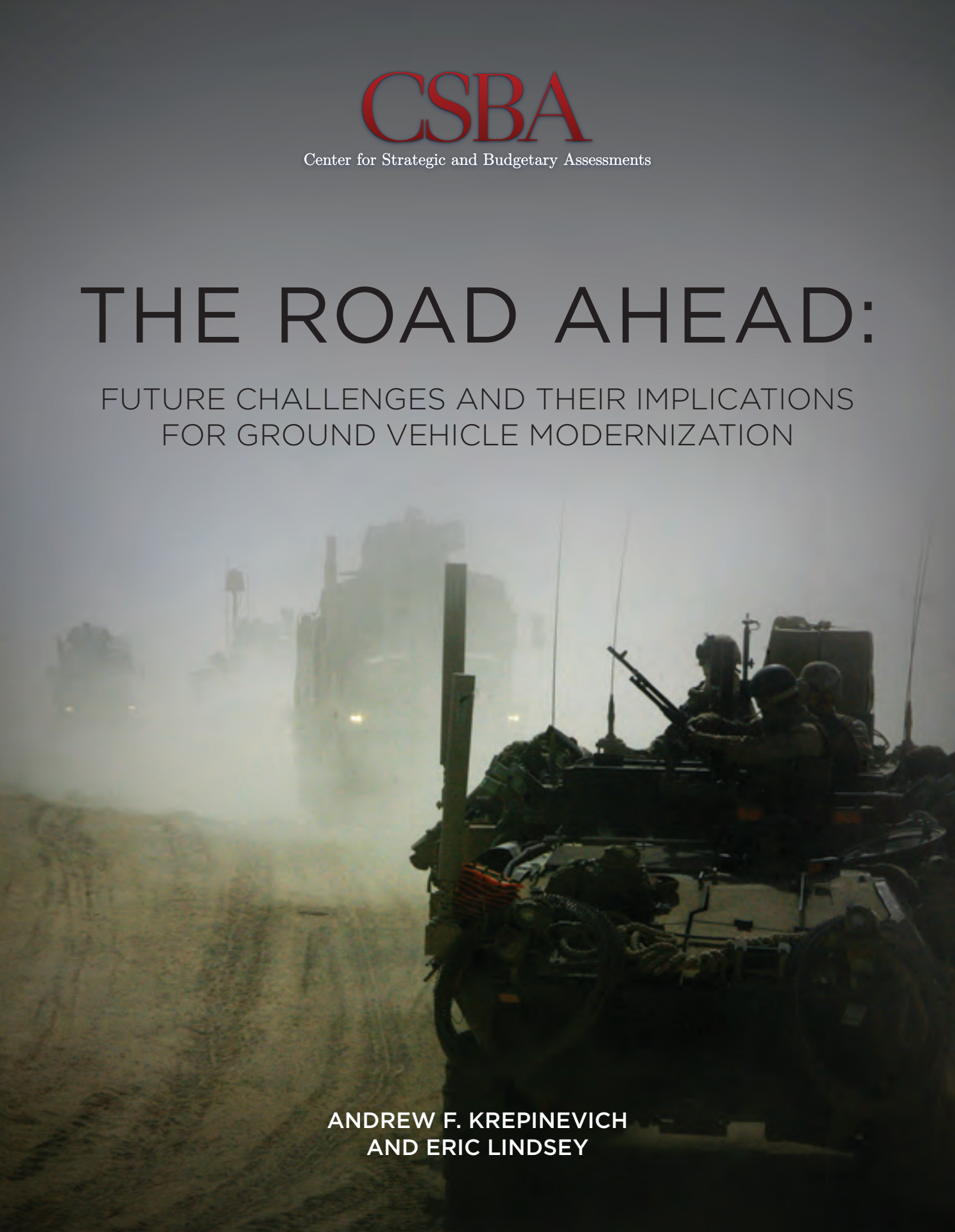
THE ROAD AHEAD:

FUTURE CHALLENGES AND THEIR IMPLICATIONS FOR GROUND VEHICLE MODERNIZATION



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About the Authors

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CONTENTS

EXECUTIVE SUMMARY

This report provides a context within which to consider the U.S. Army and Marine Corps modernization of ground vehicles. Both Services are in the early stages of modernizing their vehicle fleets. These modernization efforts will be severely constrained by the budget cuts looming over the Department of Defense. The brunt of these cuts will likely fall on the Services' modernization accounts. This, combined with their aging inventory of ground vehicles, makes it imperative that the Army and Marine Corps anticipate as best they can the changing character of land warfare over the next 10-20 years.

Although attempting to predict the future amounts to a fool's errand, it is possible to reduce risk and hedge against the surprises that will inevitably occur. A careful analysis of trends can identify emerging changes in the security environment that are likely to have significant implications for U.S. ground forces. Such an analysis will provide insights as to how best to proceed with upgrading or replacing the current inventory of ground vehicles.

There are seven trends that seem likely to exert significant, and in some cases major, influence on the character of land warfare in the coming decades and, by extension, Army and Marine Corps vehicle requirements:

> The evolution of the armor/anti-armor competition, which will likely remain dynamic with the advantage fluctuating between anti-vehicle weapons and vehicle protection. That said, the competition seems likely to consistently favor the offense in that, given equal resources, it will be far cheaper to develop capabilities to defeat vehicle protection than it will be to develop new means to protect ground combat vehicles;

> The proliferation of precision-guided weaponry, which will likely give both state and non-state adversaries access to guided rockets, artillery, mortars and missiles, or G-RAMM;

- The prevalence of nonlinear operations, which will likely deny U.S. ground forces operational sanctuary not only in secure rear areas of the battlefield, but also in other physical domains, such as outer space, and in non-physical areas of operation, such as the electromagnetic spectrum and cyber space;
- The urbanization of warfare, as the growth of urban areas proceeds apace and adversaries look to exploit this terrain to minimize U.S. forces' advantages in open battle;
- The proliferation of nuclear weapons in the developing world;
- The U.S. emphasis on force protection, which will persist despite the expense and difficulty of doing so on an increasingly lethal battlefield; and
- The growing importance of U.S. allies and partners within a strategy designed to build up their ground forces' capabilities (i.e., "building partner capacity"), with many having substantially different ground vehicle design priorities than the Army or Marine Corps.

As these trends play out, they will almost certainly pose serious challenges to the way the U.S. Army and Marine Corps currently deploy, fight, and sustain themselves in power-projection operations. They suggest that the future operational environment will, generally speaking, be far more lethal than has been the case for U.S. ground forces in recent conflicts. Adversaries' use of guided weapons, relatively cheap and rapidly fielded anti-armor weapons, urban warfare within the framework of an anti-access/area-denial (A2/AD) posture threatens to increase significantly the costs incurred by U.S. ground troops in accomplishing their assigned missions.

At the same time, force protection will likely remain an imperative. In the future operational environment described here, heavy vehicles, such as tanks, infantry fighting vehicles, and wheeled vehicles that can provide high levels of protection, will remain valued assets. However, deploying and sustaining these heavy, logistically-demanding vehicles will likely grow more difficult should adversaries field A2/AD capabilities in greater numbers, and/or obtain nuclear weapons, enabling them to pose a greater threat to deployment and sustainment operations. This poses a dilemma that ground vehicle modernization is unlikely to solve by itself.

Given these considerations, this paper recommends the following general approach to ground vehicle modernization:

The Army and Marine Corps should develop operational concepts that will inform how they plan to deploy, fight, and sustain themselves in the operational environment that will likely emerge as a consequence of the trends described above. As with the AirLand battle operational concept developed in the

1980s, this effort should involve close cooperation among all four Services, as the Air Force and Navy will almost certainly play a major role in supporting any significant U.S. ground force power-projection operation.

First, given prospective resource constraints, the ground forces should seek to "use it up, wear it out, make it do, or do without" whenever possible.

Over the past decade, the Army and Marine Corps have pursued a multifaceted effort, funding ambitious development programs, extending the service lives of existing vehicles, and fielding readily available "off-the-shelf" vehicles. Generally, top priority has been given to fielding a new generation of vehicles.

Second, the ground Services should do the opposite, pursuing recapitalization and off-the-shelf solutions whenever possible, upgrading existing systems as much as possible, and undertaking ambitious developmental efforts only when there is a high assurance that the new system will provide a discontinuous boost to ground forces' combat effectiveness.

Third, if and when developing next-generation vehicles becomes necessary, the Army and Marine Corps should accord high priority to maximizing these vehicles' adaptability by pursuing an open-architecture approach and deliberately designing in surplus space, weight, and power (SWaP) in order to facilitate future modification. Ideally, these vehicles would not only have "room to grow" to meet future needs, but also the ability to "shrink" (i.e. shed capability) in order to better suit the needs of allies and partners that may have significantly different vehicle requirements (e.g., greater resource constraints; relatively unsophisticated manpower pools; lower force protection standards).

Fourth, while conserving resources and leveraging past investments, the ground Services should not neglect their future. Science and technology (S&T) funding is the "seed corn" of future capabilities, and protecting it should be a priority. The challenges presented in this study suggest several candidate areas for heavy S&T investment, including novel protection measures (e.g. active protection) that could increase vehicle survivability without increasing vehicle weight; enhanced fuel efficiency improvements (e.g. hybrid-electric propulsion) that could decrease the logistics burden; and robotic systems (e.g. those enabling remote or autonomous vehicle operation) that could reduce force protection demands, as well as the number of troops required for deployment and their associated sustainment demands. Although these technologies appear promising, substantial investment may be required before they mature enough to be affordably incorporated into new or existing vehicles. This strengthens the case for putting off developing a new family of ground vehicles for the time being, while pursuing a vigorous science and technology program.

Finally, decisions regarding the future of ground combat vehicles must account for the second-order effects on the defense industrial base, long a major U.S. strategic asset. Decisions should be made with an eye toward preserving key sectors of the industrial base during what appears to be a protracted period

of fiscal austerity. Absent a capable and responsive industrial base, many of the points made above regarding how best to proceed with planning for the long-term posture of U.S. ground vehicles become moot. Accordingly, the Army and Marine Corps should identify the most critical sectors of the ground vehicle industrial base and make a deliberate effort to sustain them.

INTRODUCTION

> Uncertainty is necessarily the lot of the planner, since he deals with the future. Uncertainty can never be completely removed. However, it can be compensated for, and to do so is a continuing responsibility of those who plan military forces. Primarily this can be done by insuring, in so far as we can, that future weapons and forces will be adaptable to the right range of defense needs.[1]
>
> —Harold Brown, 1967

For nearly a century, motorized vehicles have been among the most important pieces of equipment operated by the U.S. Army and Marine Corps. Since 1916, when General John Pershing and the Punitive Expedition entered Mexico in pursuit of Pancho Villa supplied by a fleet of 54 newly-acquired 1½-ton trucks,[2] vehicles have been a key enabler of U.S. military operations, providing American ground forces with enhancements to their lethality, survivability, and mobility. Such enhancements come at a price, however; vehicles are among the mostly costly pieces of equipment in the Army and Marine Corps inventories. Vehicles thus constitute a significant investment for both Services, both of whom refer to their vehicles as "capital" and to their vehicle fleets as "portfolios." These economic analogies are appropriate. Like capital, vehicles are acquired to provide value over an extended period of time. Like investment portfolios, the composition and value of the Army and Marine Corps vehicle fleets should therefore be viewed from a long-term perspective.

Today, after a decade of intensive ground operations overseas, both the Army and the Marines face important vehicle modernization issues. Addressing these will entail meeting two central planning challenges, the first being the inherent

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[1] *Harold Brown, "*Planning Our Military Forces*," Foreign Affairs,* 45, No. 2, January 1967.

[2] This was the first procurement and use of motorized vehicles on a significant scale by the U.S. military. See Albert Mroz, *American Military Vehicles of World War I* (Jefferson, NC: McFarland & Co., 2009), pp. 50-75.

uncertainty regarding the future security environment (i.e., where and under what conditions tomorrow's ground forces must be able to fight and win), and the second a function of an austere contemporary economic and budgetary environment that may exist for an extended period. This study provides a way of thinking about the Army and Marine Corps vehicle portfolios, and suggests some issues that merit attention from those tasked with determining their composition.

Toward this end, it identifies seven key trends that offer insights into the future land combat environment, and that should be taken into account in assessing the current inventory of ground combat systems as well as future requirements. That said, those seeking a detailed prescription for the precise type and number of ground combat vehicles that should comprise the future Army and Marine Corps inventories will be disappointed. To employ a medical analogy, this study focuses primarily on a diagnosis of the environment and a prognosis of the key factors that should inform the thinking of those tasked with writing the "prescription," i.e., making the specific investment decisions about the future Army and Marine Corps vehicle capital stocks. To extend the metaphor, the range of possible "prescriptions" may be constrained by funds that are made available.

The world is undergoing geopolitical, economic and military-technical changes at a remarkable rate.

THE CHALLENGE OF UNCERTAINTY

Army and Marine Corps vehicles can have service lives lasting decades. Assessing the future value of particular vehicle types over such extended periods, particularly in a highly dynamic security environment, is a difficult undertaking since the future conditions under which U.S. ground forces will operate are inherently uncertain. The world is undergoing geopolitical, economic and military-technical changes at a remarkable rate. Political changes are sweeping through many regions, particularly the Middle East, one of the world's most unstable but strategically important regions. Economic and financial turmoil—the worst in decades—is accelerating the redistribution of economic power from West to East, while threatening to plunge the global economy into a period of protracted stagnation. Science and technology are progressing and diffusing at an accelerating pace, opening up new fields of scientific exploration and proliferating advanced technologies to the developing world. In the military sphere, potential adversaries are challenging America's long-standing lead in key technologies central to current and emerging areas of the military competition. In some cases, even individuals or small groups of terrorists, criminals, and other non-state actors are acquiring and employing capabilities formerly the preserve only of nation-state militaries. Both state and non-state actors are developing new methods of waging war—and adapting old ones—to upset the established military balance.[3]

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[3] Andrew Krepinevich, "Get Ready for the Democratization of Destruction," *Foreign Policy*, September/October 2011.

Thus it is impossible to predict what the future security environment will look like a decade hence, let alone in 20 or 30 years. Yet an effort must be made to understand the range of plausible possibilities. This can help identify characteristics most likely to maximize vehicle effectiveness over its expected service life while hedging against disruptive shifts in the character of land warfare. Deferring such decisions indefinitely in hopes of gaining greater clarity about future threats generally is not useful. No matter when defense planners make their decisions, given the long development times—seven years is the current aspiration to field a new system for several programs—and the even longer expected service lives of ground vehicles, those choices will determine the vehicles the ground forces will take into combat two or more decades thereafter. Thus, there is no premium for waiting.

For example, consider the case of the ubiquitous High-Mobility Multipurpose Wheeled Vehicle, or "Humvee."[4] These vehicles—designed to be unarmored or only lightly armored—have been much maligned for the inadequate protection they provide against the roadside improvised explosive devices (IED) employed by forces in Iraq after the U.S. invasion of that country in March 2003. Yet, development of the Humvee began in 1979, nearly a quarter century earlier when the requirements of mechanized warfare against the Warsaw Pact in Central Europe were the key design drivers. A lightweight, unarmored vehicle—the Humvee—with an aluminum hull was ideal for the transport and communications roles it was anticipated to perform in secure areas behind the front lines.

Twenty-five years later, however, the operational environment and requirements had changed dramatically, but the Humvee remained essentially the same. When asked in 2004 why nothing else was available, then Secretary of Defense Donald Rumsfeld replied, "You go to war with the Army you have—not the Army you might want or wish to have at a later time."[5] Rumsfeld's remark was perceived as insensitive, but his words reflected the fundamental reality of vehicle procurement. The decisions regarding the kinds of vehicles American soldiers and marines initially had available in Afghanistan and Iraq had in most cases been made a quarter century before.

What Should and Should Not Be Attempted

The wars in Iraq and Afghanistan, of course, were unforeseeable in 1979. But the engagement of U.S. ground forces in irregular warfare—which had occurred on a large scale only a few years before in Vietnam—was not, nor was the use

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[4] The High-Mobility Multipurpose Wheeled Vehicle (HMMWV), or "Humvee," is a 1¼-ton truck with multiple variants and hundreds of thousands of vehicles in use by all four services. Its manufacturer's claim that "Wherever American soldiers go, their Humvees go with them" is essentially accurate.

[5] Thomas E. Ricks, "Rumsfeld Gets Earful From Troops," *Washington Post*, December 9, 2004.

Defense planners should consider a representative range of plausible futures to help them identify and prioritize key design factors for new ground combat vehicles, and then make the necessary trade-offs among them.

of roadside bombs by the enemy—also encountered in Vietnam[6] and elsewhere.[7] While one cannot predict the future with any degree of fidelity and specificity, it *is* possible to identify and explore potential developments and trends that may significantly alter operational requirements for future combat operations. It is also useful to assess other relevant potential developments which, although perhaps less likely to transpire, could have such grave consequences they should be taken into consideration despite their improbability. If defense planners and vehicle designers actively consider and account for these factors in their vehicle designs, procurement plans and operational concepts, they may reduce the odds of costly surprises down the road. Simply put, rather than futilely trying to predict the future, defense planners should consider a representative range of plausible futures to help them identify and prioritize key design factors for new ground combat vehicles, and then make the necessary trade-offs among them.

Given the inherent uncertainty of the future operational environment, it has been argued that "it makes little sense to spend time determining what capabilities will be needed for an unseen and unknowable future…" and that the ground forces should "incrementally develop the current [force] based on the [current] operating environment, near-term future trends and realistic expectations" instead of attempting to incorporate thinking about the more distant future.[8] These arguments often highlight the failure of the Army's Future Combat Systems (FCS) program as a cautionary tale of what can happen when visions of the future play too large a role in vehicle procurement decisions. The problem with the FCS program, and particularly its Manned Ground Vehicles (MGV) component, was not that its proponents had spent too much time thinking about the future, but rather that they had spent too little time thinking about how the future could deviate from their anticipated course of events. The Army's narrow assumptions regarding the future land warfare environment, focusing primarily

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6 Mines and improvised explosives caused roughly a third of U.S. casualties in Vietnam. In a 1969 letter to the Army's Chief of Research and Development, the Deputy Commanding General in Vietnam wrote that "Vietnam has seen the emergence of mines as a major weapons system, used on a scale, relatively speaking, never before encountered… *the lessons we have learned here in Vietnam should not be interpreted as an isolated problem peculiar to this war only* [emphasis added]." Human Rights Watch, "In Its Own Words: The U.S. Army and Antipersonnel Mines in the Korean and Vietnam Wars," July 1997, available at http://www.hrw.org/reports/1997/gen1/General-03.htm#P156_21327, accessed on January 30, 2012.

7 The contemporary experiences of South African forces in the "bush wars" might have offered another hint of what was to come. Between 1972 and 1980, there were 2,540 instances of vehicles striking mines placed by ZANLA insurgents in Rhodesia. The South African Army began acquiring MRAPs in 1974. See Keith Campbell, "South Africa's armored vehicle success steeped in impressive, design, manufacture history," *Engineering News*, October 10, 2008, available at http://www.engineeringnews.co.za/article/ south-africas-armoured-vehicle-success-steeped-in-impressive-design-manufacture-history-2008-10-10; and J.R.T. Wood, "Rhodesian Insurgency," available at http://www.rhodesia.nl/wood2.htm, accessed on February 7, 2012.

8 Eric A. Hollister, *A Shot in the Dark: The Futility of Long-Range Modernization Planning* (Arlington, VA: Association of the United States Army, 2010), p. 6.

on open battle against a traditional combined-arms mechanized adversary, was similarly unfortunate.[9] Here Army planners fell into the trap of placing heavy emphasis on a single, relatively favorable vision of the future, while discounting other plausible futures.

In order to avoid such missteps in the future, defense planners and vehicle designers need to adopt a more balanced and comprehensive approach to thinking about ground vehicle modernization. Such thinking must take into consideration the uncertainty inherent in the future rather than ignoring it or assuming it away by attempting to optimize ground vehicles around a particular vision of the future conflict environment, thereby risking a single point of failure. Such thinking must also feature more realistic assumptions about resource availability and rates of technological maturation.

A Crossroads for Vehicle Procurement

The need for such thinking is urgent. Today, both the Army and the Marine Corps are in the early stages of ambitious efforts to recapitalize their vehicle fleets by replacing aging vehicles with newer, more capable models. This is not the first attempt for either Service to replace elements of the existing fleet. Earlier efforts by the Army in the form of its FCS Manned Ground Vehicles program and by the Marine Corps in its pursuit of the Expeditionary Fighting Vehicle (both mentioned above) ended with the programs' cancellation, in large measure due to their high cost, programmatic delays, and overly optimistic expectations regarding how quickly key technologies would mature.[10]

While those programs were in development, both Services had to undertake crash procurement of mine-resistant, ambush-protected vehicles (MRAPs) and MRAP all-terrain vehicles (M-ATVs), at a cost of over $40 billion, to meet the immediate needs of troops in Iraq and Afghanistan.[11] On the positive side, this demonstrated the two Services' ability to field ground vehicles in large numbers and quickly. At the same time, the urgency with which these vehicles were procured in response to the immediate IED threat meant they were not designed with affordability in mind. Nor were they well-suited to operate in environments and against threats much different than those for which they were acquired. Thus, the Army and Marine Corps view MRAPs and M-ATVs as temporary stopgaps, "single-point solutions" with highly limited utility for other contingencies.

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[9] Andrew Krepinevich, *Transforming the Legions: The Army and the Future of Land Warfare* (Washington, DC: Center for Strategic and Budgetary Assessments, 2004), pp. ii-iii.

[10] Robert M. Gates, "Defense Budget Recommendation Statement," Arlington, VA, April 6, 2009, available at http://www.defense.gov/speeches/speech.aspx?speechid=1341.

[11] For a succinct overview of the MRAP and M-ATV programs, see Andrew Feickert, "Mine-Resistant, Ambush Protected (MRAP) Vehicles: Background and Issues for Congress," Congressional Research Service, January 18, 2011.

The Pentagon will not be able to adopt a "cost is no object" attitude toward any program, especially when the Department of Defense (DoD) confronts what is likely to be a prolonged period of fiscal austerity.

The rapid acquisition of these vehicles undoubtedly saved many lives, but it does not constitute a good model for how peacetime acquisition programs should proceed. Many ground vehicles are considerably more complex than MRAPs and must be able to perform a wider set of missions across a range of contingencies. Thus, they cannot be developed and procured quickly. Just as important, the Pentagon will not be able to adopt a "cost is no object" attitude toward any program, especially when, as described later in this report, the Department of Defense (DoD) confronts what is likely to be a prolonged period of fiscal austerity.[12]

Current Army plans call for replacing the M2 Bradley infantry fighting vehicles with a new Ground Combat Vehicle (GCV) and replacing the remaining "family of vehicles" based on the M113 armored personnel carrier with a new set of vehicles based on a common Armored Multi-Purpose Vehicle (AMPV). The Marine Corps plans to replace its Amphibious Assault Vehicle (AAV) with a new Amphibious Combat Vehicle (ACV) and develop a separate Marine Personnel Carrier (MPC) for use ashore. Both Services also plan to modernize their tactical wheeled vehicle (TWV) fleets by "recapitalizing" (i.e., overhauling and enhancing) some of their "Humvees" while replacing others with a new Joint Light Tactical Vehicle (JLTV). None of these programs have reached "Milestone B," the point at which a design is selected for production. All are to be funded more or less concurrently.

THE CHALLENGE OF AUSTERITY

This is likely to prove a difficult undertaking in the current fiscal environment. After more than a decade of increasing defense budgets, DoD now must plan for $487 billion in cuts over the next decade, with still more substantial cuts possible. In this environment, the competition for programmatic dollars will be fierce. What one observer has called "the biggest military food fight in at least a generation" may already be underway.[13] Additionally, both policymakers[14] and

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[12] At least one DoD program manager agrees, finding that "The almost perfect alignment of favorable circumstances that contributed to the success of the program—consistent support from the highest level and an *almost unlimited budget* [emphasis added]—cannot be replicated on most acquisition programs." Thomas H. Miller, "Does MRAP Provide a Model for Acquisition Reform?" *Defense AT&L*, July/August 2010.

[13] Dan Goure, "Coming Cuts May Put Services At Each Other's Throats," *AOL Defense*, September 14, 2011.

[14] Secretary Gates, for example, told the Senate Appropriations Committee that he was "determined that we not repeat the mistakes of the past, where the budget targets were met mostly by taking a percentage off the top of everything… That kind of 'salami-slicing' approach preserves overhead and maintains force structure on paper, but results in a hollowing-out of the force." Remarks delivered by Robert Gates, "Opening Summary – Senate Appropriations Committee – Defense (Budget Request)," Washington, D.C., June 15, 2011.

outside experts[15] are making the case that in lieu of "salami slicing" (i.e., cutting each Service's budget by a proportionately similar amount), DoD should make "hard decisions,"—cutting some programs, capabilities, and force structure elements outright, while leaving higher priority programs intact. With U.S. ground forces having completed their withdrawal from Iraq and continuing to draw down in Afghanistan, the decade-long stresses on the Army and Marine Corps are abating. Polls show that the American public has little stomach for another major military occupation, and the Pentagon's new Strategy Guidance declares that "U.S. forces will no longer be sized to conduct large-scale, prolonged stability operations."[16] Accordingly, a chorus of voices is calling for the Pentagon to shift funding from the forces that dominate those contingencies—the Army and Marine Corps—to other priorities.[17] This shift appears to be already underway, with reductions in Army active-duty personnel from 570,000 to 520,000[18] (and more likely 490,000) and cuts in Marine active-duty personnel from 203,000 to 186,000[19] reported as the least drastic options currently under consideration.

The most favorable case from the perspective of Army and Marine Corps planners is that cuts over the next ten years will be limited to the $487 billion currently programmed, and that these cuts will evenly divided among the Services. In this "best" case, the Army will cut $12-14 billion from its budget per year, according to the Service's comptroller, Deputy Chief of Staff (G-8) Lieutenant General Robert Lennox. As Lennox told an audience in October 2011, "the brunt [of these cuts] will come in modernization . . . . that's just math."[20] Although senior Marine leaders have expressed confidence that the Corps' "modernization

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[15] See, for example, David Barno, Nora Bensahel, and Travis Sharp, *Hard Choices: Responsible Defense in an Age of Austerity* (Washington, DC: Center for a New American Security, 2011); and Peter W. Singer, "A Defense Policy Vision: The Commander in Chief Should Set Out Goals for the Next SecDef," *Armed Forces Journal*, June 2011.

[16] See Department of Defense, *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense* (Washington, DC: Department of Defense, 2012), p. 6; and Leon E. Panetta, *Statement on Defense Strategic Guidance*, Washington, DC, January 5, 2012. See also, "Survey Report: Obama Draws More Confidence than GOP Leaders on Deficit," Pew Research Center for People & the Press, September 26, 2011. According to the Pew Research Center, 66 percent of Americans polled approved of reducing U.S. military commitments overseas in order to reduce the national debt.

[17] As one reporter has observed, "After a decade of grinding wars in Iraq and Afghanistan, the conventional wisdom is that America will have no tolerance for any more ground fights. Policy makers will take that as a cue that it is now time to shift defense dollars from infantry to high-tech weaponry that can be fired from aircraft or ships, far away from the battlefield." Sandra Irwin, Pentagon Should Think Twice Before It Cuts Ground Forces, Historians Warn," *National Defense Magazine*, October 2011.

[18] Thom Shanker, "Army Leaders Warn Against Shrinking Forces Too Much," *New York Times*, October 10, 2011.

[19] Carlo Munoz, "Marines Grope For Answers As Uncertain Future Looms," *AOL Defense*, November 18, 2011.

[20] LTG Robert P. Lennox, "Responsible and Agile Modernization for the Force of Decisive Action," remarks at the Association of the United States Army (AUSA), October 11, 2011.

profile" can be protected if cuts are made to force structure instead, they have acknowledged procurement will have to be scaled back from "those things we want" to "things we will need."[21] Should the eventual cuts exceed the $487 billion currently programmed, the impact on both Services' modernization accounts undoubtedly will be more severe.

Given these fiscal constraints, the ground forces will have to rethink their vehicle modernization plans. This will make it all the more important to avoid programs designed for single-point solutions (e.g., MRAP), or that rely heavily on ambitious technological advances (e.g. FCS), as the Pentagon will find it far more difficult to buy its way out of its mistakes than it has in the recent past.

THE ROAD AHEAD

As military historian Michael Howard has observed, sound procurement decision making requires a "triangular dialogue between … operational requirements, technological feasibility and financial capability."[22] This study seeks to promote such a dialogue by presenting a framework for *how to think about* the challenges of procuring a new generation of ground vehicles at a time of diverse emerging threats to U.S. security abroad and increasing financial austerity at home.

Accordingly, this report is structured as follows: Chapter 1 explores seven trends that may offer insight into potential challenges that the future security environment may hold. Chapter 2 considers the implications those trends may have for how U.S. ground forces deploy, fight, and are sustained, and how this in turn may inform ground vehicle requirements. Chapter 3 explores vehicle acquisition strategies to help minimize surprise and conserve scarce resources. Chapter 4 offers some concluding thoughts.

Again, this paper is *diagnostic*, not prescriptive, in nature. Its objective is not to find in favor or against certain vehicles or acquisition programs, but to identify the broader issues that should be taken into account by policy makers, military leaders and vehicle designers as they consider the road ahead for ground vehicle modernization.

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[21] Gen Joseph Dunford, Assistant Commandant of the Marine Corps, quoted in John T. Bennett, "Marines to cut troops, not weapons, to meet 2013 budget cuts," *The Hill*, December 7, 2011.

[22] Michael Howard, "Military Science in an Age of Peace," *RUSI Journal*, March 1974.

CHAPTER 1 > **TRENDS AFFECTING FUTURE GROUND COMBAT**

In October 2011, the senior Army general responsible for modernization programs described the challenges he faced to members of the House Armed Services Committee:

> One of the officers who works for me, I think, said it better than anybody else: we have kind of an unknown future, we don't know what the threats will be that the nation faces, but [we] have to be ready for those both today and tomorrow. He likens it to driving down a steep cliff in the dark, and you can only see out as far as your headlights.[23]

The analogy is an apt one.[24] Like a driver at night, a defense planner's view of the road extends only a short distance ahead. But like that driver, defense planners can get a sense of what lies ahead of the relatively small stretch of the way ahead illuminated in their headlights. Gentle contours in the road are often indications of more challenging driving ahead. The road already traversed can also give a driver some sense of what to expect. This chapter focuses on the road ahead—the prospective future ground combat environment. It identifies potential twists and turns in the road as well as possible obstacles—and sources of potential advantage—along the way.

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[23] LTG Robert Lennox, "Army Acquisition and Modernization": Testimony before the Subcommittee on Tactical Air and Land Forces, House Armed Services Committee, October 26, 2011.

[24] Former Secretary of the Navy Richard Danzig has also employed this analogy in *Driving in the Dark: Ten Propositions about Prediction and National Security* (Washington, DC: Center for a New American Security, 2011).

fundamental question: "What might land warfare be like during this period?" This in turn prompts others:

> Whom, when, where, and for what might U.S. ground forces be called upon to fight?

> How would this influence ground force operational concepts and doctrine?

> What can we infer from this regarding the design of ground combat vehicles?

These questions cannot be answered with certainty. But based on a rigorous assessment of enduring U.S. interests and current geopolitical trends, planners can offer educated guesses regarding a set of plausible future conflict scenarios. Done well, this process will not eliminate surprise and uncertainty. However, it may reduce the chances of serious surprises, curtail risk, and enable a more adaptive response if and when surprise does occur.

THE FUTURE ROLE OF GROUND FORCES

With the drawdown of U.S. ground forces in Afghanistan and Iraq, the American public and many policy-makers show little appetite for major ground force commitments for the foreseeable future. Even former Secretary Gates, who during his Pentagon tour was a self-proclaimed "friend of ground forces,"[25] echoed such sentiments in a speech to the cadets at West Point. Looking ahead to "the competition for tight defense dollars within and between the Services," Gates warned the Army to "confront the reality that the most plausible, high-end scenarios for the U.S. military are primarily naval and air engagements—whether in Asia, the Persian Gulf, or elsewhere," and that, in the outgoing Secretary's opinion, "any future defense secretary who advises the president to again send a big American land army into Asia or into the Middle East or Africa should 'have his head examined,' as General MacArthur so delicately put it."[26] The strategic guidance publicly delivered by the President, Secretary, and Chiefs of Staff in January 2011 suggests that the nation's senior civilian and military decision makers have heeded Gates' advice.[27]

It is understandable that defense policy makers would seek to avoid becoming involved in a major land war—in Asia, or elsewhere—along with the high costs in blood and treasure they typically entail. But seeking to avoid such situations and being able to do so are two different things. As senior military leaders are fond of saying, "the enemy gets a vote." Just as U.S. policy-makers sought to

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[25] Joseph J. Collins, "Message to the Next SecDef: How to Navigate the Defense Downturn," *Armed Forces Journal*, 148, No. 8, April 2011, pp. 27-28, 38.

[26] Robert M. Gates, Remarks at United States Military Academy, West Point, NY, February 25, 2011.

[27] Department of Defense, *Sustaining U.S. Global Leadership.*

avoid fighting a major counterinsurgency campaign in the decades following the Vietnam War, it may not be possible to avoid under all circumstances. Air and naval power have demonstrated the ability to achieve impressive results when coordinated with the actions of special operations forces or indigenous ground forces, but there are limits to their capability and capacity to project power and influence events ashore.

Indeed, in some situations there is no substitute for the capabilities provided by large-scale ground forces. As one analyst notes,

> Ground forces can seize and hold terrain, separate hostile groups, and comb through urban areas with infinitely greater precision and distinction between combatant and non-combatant than airpower. They can present the enemy with unacceptable situations simply by occupying a given piece of land, forcing the enemy to take actions that reveal intentions and expose the enemy to destruction. And it goes without saying that only ground forces can execute the peacemaking, peacekeeping, and reconstruction activities that have been essential to success in most of the wars America has fought in the past hundred years.[28]

Ground forces remain essential to exercise control on land. Air and naval forces can deny an adversary the ability to occupy an area, but only ground forces can provide positive control of an area and its inhabitants.

In short, ground forces remain essential to exercise control on land. Air and naval forces can deny an adversary the ability to occupy an area, but only ground forces can provide positive control of an area and its inhabitants. Detractors may point to the cost of achieving such control. As has been demonstrated in Iraq and Afghanistan, it can indeed be high.[29] Others may argue that partner forces with convergent interests may be substituted in place of U.S. ground forces and supported by other elements of the joint force. Ultimately, however, the U.S. military must remain prepared for situations in which positive control of an area and its inhabitants is required, but control by partner forces with convergent interests is infeasible or insufficient to accomplish the mission. As Army General Martin Dempsey, Chairman of the Joint Chiefs of Staff stated, the United States is "a global power, and we have to be able to conduct military activities and operations across the full spectrum… Nobody has said and nowhere in the [strategic guidance] document does it say we're not going to fight land wars."[30]

Those who would argue the United States simply would not commit large ground forces for the foreseeable future should consider how much the world can change even in a short period of time.

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[28] Frederick W. Kagan, "The Art of War," in Paul J. Bolt, Damon V. Coletta, *American Defense Policy*, and Collins G. Shackel, ed. (Baltimore: The Johns Hopkins University Press, 2005), p. 237.

[29] In addition to the human costs mentioned above, the wars in Iraq and Afghanistan have cost the United States approximately $1.3 trillion in FY 2012 dollars. Todd Harrison, *Analysis of the FY 2012 Defense Budget* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011), p. 6.

[30] Martin Dempsey, Defense Strategic Guidance Briefing from the Pentagon, Washington, DC, January 5, 2012.

As Secretary Gates himself noted at West Point,

> When it comes to predicting the nature and location of our next military engagements, since Vietnam, our record has been perfect. We have never once gotten it right, from the Mayaguez to Grenada, Panama, Somalia, the Balkans, Haiti, Kuwait, Iraq, and more—we had no idea a year before any of these missions that we would be so engaged.[31]

Nor can U.S. planners hope to predict with accuracy the characteristics of future conflicts, although they can work to reduce the prospects of being surprised. An essential part of accomplishing this involves identifying and keeping abreast of trends that may affect the conduct of operations in the decades ahead.

SEVEN TRENDS

This paper identifies key trends in seven areas likely, either alone or in combination, to pose significant challenges to ground forces and their vehicles. Taken together, these present a plausible "worst case" environment for future land combat. This is intentional. If defense planners and vehicle designers can address the most stressful plausible future land warfare environment, this will increase the chances that future U.S. ground forces will be both resilient and effective across a range of contingencies. The seven areas are the:

> Evolution of the armor/anti-armor competition;

> Proliferation of precision-guided weapons;

> Prevalence of the non-linear battlefield;

> Urbanization of warfare;

> Proliferation of nuclear weapons;

> U.S. prioritization of force protection; and

> United States' growing reliance on allies and partners.

1) THE EVOLUTION OF THE ARMOR/ANTI-ARMOR COMPETITION

Although the threat posed to U.S. forces by IEDs caught the ground forces largely unprepared when it appeared in 2003, the threat posed to vehicles by anti-tank (or anti-armor)[32] weapons is not new. The employment of increasingly powerful and

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[31] Gates, Remarks at United States Military Academy.

[32] "Anti-tank" is the term applied to weapons designed to defeat armored vehicles in general, including but not limited to tanks. They are also effective (often even more so) against unarmored vehicles.

sophisticated IEDs against U.S. vehicles by insurgents in Iraq and Afghanistan is simply the latest iteration of a dynamic measure-countermeasure competition in which the advantage has continually fluctuated between anti-vehicle weapons and vehicle defenses. This competition may remain dynamic in the future. However, at present, it clearly seems likely to favor the anti-armor forces, both on technical and cost imposition grounds. Put another way, absent some major breakthrough in armor defenses, protecting armored vehicles (let alone unarmored ground vehicles) is likely to cost far more to accomplish than the costs incurred by those seeking to destroy or neutralize these vehicles.

Therefore, as anti-armor weapons continue to evolve, it is unlikely that vehicle defenses, whether in the form of armor or other measures, will be able to provide a high level of protection for any lasting period of time. This has historically been the case. During World War II, the dawn of *Blitzkrieg* warfare, both tank armor and anti-tank weapons saw remarkable growth and innovation. Developments in each area effectively kept pace with one another, with new measures implemented in one area prompting rapid countermeasures in the other. Despite the fact that tank armor thickness roughly quadrupled during the course of the war,[33] increases in the caliber and velocity of anti-tank guns and other novel developments, such as the shaped charge warhead and the rocket launcher, meant tanks remained vulnerable throughout the war despite their thicker armor.

Absent some major breakthrough in armor defenses, protecting armored vehicles is likely to cost far more to accomplish than the costs incurred by those seeking to destroy or neutralize these vehicles.

The Cold War saw a similarly dynamic measure-countermeasure competition in which various protective measures capable of defeating existing anti-tank weapons were surpassed by new anti-tank weapons, which in turn stimulated new forms of protection. In 1984, for example, the U.S. Army introduced the M829 depleted uranium "sabot" round, which promised to be able to penetrate the thickest Soviet tank armor. The round performed extraordinarily well against Soviet-made tanks used by Iraq in the 1991 Gulf War, earning the nickname "silver bullet." After the end of the Cold War, however, Western engineers examined tanks equipped with Russian *Kontakt*-5 explosive reactive armor (ERA), which had been in service since 1985 in the Soviet Army, and found that it made them effectively "immune" to the M829.[34] Thus the "silver bullet" had already been rendered significantly less effective (if not yet obsolete) only a few years after it had entered service. In response, improved A2 and A3 variants of the M829 have since been developed, and have better performance against *Kontakt*-5. But this development too is unlikely to go unanswered; Russian manufacturers report-

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[33] For example, the Panzer IIC, which was a mainstay of the German armored forces in 1939 and 1940, had 14.5 mm of frontal hull armor, while late war Panther tanks had 80 mm. Late war heavy tanks like the Tiger and King Tiger featured still more armor. "Panzerkampfwagen II" and "Panzerkampfwagen V Panther," *achtungpanzer.com*, available at http://www.achtungpanzer.com/panzer-profiles-1917-1945, accessed on October 29, 2011.

[34] Richard Ogorkiewicz, "Impenetrable Russian Tank Armour Stands Up to Examination," *Jane's International Defence Review*, July 1997, p. 15.

edly are already introducing a countermeasure, "*Kaktus*" ERA, the performance qualities of which are not publicly known.

Lasting protection for armored vehicles appears likely to remain elusive. The laws of physics dictate that, absent major advances in materials science, additional armor protection entails additional vehicle weight, with adverse effects on deployability, mobility, and sustainability.[35] Active protection systems, which intercept incoming threats before they reach their target, are currently the subject of great interest, but to date have not been able to effect a "break out" capability against the latest anti-armor threats. Moreover, although these systems are not yet in widespread use,[36] they are already being countered by anti-tank weapons in development. The Russian RPG-30, for example, is being specifically designed to counter active protection systems. Its mechanism for defeating active protection systems, moreover, is remarkably simple—the warhead is preceded in flight by a dummy warhead intended to draw the attention of the target's active protection system, thereby defeating its ability to engage the actual one.[37] As one analyst observed when this new weapon was unveiled,

> The battle between offense and defense never ends. Guns get bigger and armor gets bigger. This is another round of that, although one of the things that is significant is that the countermeasure is out before the measure is out.[38]

Significantly, nation states with sophisticated research and manufacturing bases are not the only ones keeping pace in this ongoing measure-countermeasure competition. Insurgents in Iraq and Afghanistan have proven themselves capable of keeping up in an armor/anti-armor competition despite their modest means, countering U.S. countermeasures by increasing the size of IEDs (e.g., by using larger military munitions and "daisy-chaining" several smaller pieces of ordnance together), developing innovative placement and triggering options, and employing shaped-charge weapons known as explosively formed penetrators (EFPs).[39] In response, U.S. forces in Iraq and Afghanistan employed still more armor protection and other defensive measures such as detonation signal jammers. Unfortunately, those protective measures are several orders of magnitude more expensive than the IEDs they are designed to defeat. This disparity allows irregular adversaries to impose

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35 All other factors being equal, heavier vehicles require more fuel to operate.

36 Only the Israeli Trophy system has entered service in the field.

37 Kris Osborne, "Russia Unveils Anti-APS RPG," *Army Times*, December 18, 2008.

38 Dan Goure, quoted ibid.

39 Upon impact, the detonation of the explosives in these weapons forms a slug of molten metal that is extremely dense and, propelled forward by the blast, is capable of penetrating heavy armor. It is worth noting that the materials and know-how required to employ these weapons were imported from Iran, not indigenously developed. In light of their widespread use by military forces around the world and several instances of use by terrorist groups (the Red Army Faction and Hezbollah), however, it seems likely that they will appear in the arsenals of other non-state adversaries.

highly disproportionate costs upon the United States relative to their own. Thus the expensive approach the U.S. was forced to adopt is hardly a prescription for competing effectively against state adversaries with far greater resources than irregular forces, especially in the face of growing resource constraints in an austere budgetary environment.

Worse, radical non-state groups appear to have few qualms about sharing their technology and tactics with the rest of the world, enabling faster adaptation and wider proliferation of serious anti-armor threats. One recent study of IED employment in Afghanistan identified "a phenomenon of generalized and global TTP [tactics, techniques, and procedures] acceleration in which generations of terrorists and insurgents take progressively shorter periods of time to realize advances in IED TTPs, supported by information-sharing and training among fighters and improvements in available components."[40] It took the Irish Republican Army 30 years to go from detonating IEDs by wire to detonating them remotely. "By contrast," one expert noted, "it took about six years for militants to make the same improvements in Chechnya, three year for fighters in Gaza, and about 12 months for insurgents in Iraq."[41] Indeed, the IED phenomenon appears to be spreading. According to Pentagon data, IEDs were used in 99 different countries between January and September 2011. As Lieutenant General Michael Barbero, director of the Joint IED Defeat Organization (JIEDDO), said, "If we think it's going to go away after Iraq and Afghanistan, we're dreaming."[42]

The IED phenomenon appears to be spreading. According to Pentagon data, IEDs were used in 99 different countries between January and September 2011.

Bottom line: A dynamic measure-countermeasure competition is likely to persist in which the advantage fluctuates between anti-vehicle weapons and vehicle defenses. No level or armor, or other form of protection, is likely to provide lasting effectiveness, while improvements to vehicle survivability will likely be more expensive to field than the anti-armor weapons they are designed to provide protection against. In terms of costs imposed on those attempting to keep up, the armor/anti-armor competition appears likely to continue favoring the later, and by a significant margin.

2) THE PROLIFERATION OF PRECISION-GUIDED WEAPONS

Since the dawn of warfare, the accuracy of missile weapons[43] has largely been dependent on their range from the target. A sling was more accurate against closer targets than those more distant; the same was true of the bow, the catapult,

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40 Alec Barker, *Improvised Explosive Devices in Southern Afghanistan and Western Pakistan, 2002-2009* (Washington, DC: New America Foundation, 2010), pp. 2, 16-17.

41 Alec Barker quoted in Greg Grant, "Afghan IEDs Show Rapid Adaption," *DoDBuzz.com*, April 12, 2010.

42 Tom Vanden Brook, "IED Attacks Increase Outside of Afghanistan, Iraq," *USA Today*, October 19, 2011.

43 By definition, a missile is "an object that is forcibly propelled at a target, by hand or mechanically," though the term in modern parlance refers strictly to the self-propelled guided weapons.

the cannon, the musket, the rifle, and the rocket. This made it essential for land forces employing missile weapons (as nearly all did) to close with the enemy and to compensate for inaccuracy with massed fires. These requirements dictated battlefield tactics for millennia.

Since the mid-20th century, however, technological advances have enabled progressively greater accuracy of various missile weapons systems independent of the range to their targets.[44] Although such accuracy independent of range represented a revolutionary change in warfare,[45] this capability did not suddenly arrive, but was slowly developed through efforts extending over decades. Since the Second World War, the U.S. military has been the leader in the area of precision-guided weapons (PGWs), particularly since the 1970s.[46] Over the past three decades, it has enjoyed a near monopoly on PGWs, employing them with growing effect in the First Gulf War, the 1999 Balkan conflict, and more recently in Afghanistan and Iraq.[47] Unfortunately, the U.S. edge in precision-guided weaponry appears to be eroding as PGWs of various kinds are proliferating widely to both state and non-state actors.

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In land warfare, this trend is likely to manifest itself most significantly in the proliferation of two broad categories of PGWs with varying ranges and capabilities:

"Theater G-RAMM" comprise cruise and ballistic missiles with ranges in the multiple tens or even hundreds of miles. These could strike targets throughout the theater of operations (or at least large portions of it). Although these systems would have *accuracy independent of range* by definition, they would not have *range independent of cost* due to the system capabilities required to provide such range (e.g., propulsion systems, fuel, targeting support, and so forth). Thus they likely will remain considerably much more expensive than battlefield G-RAMM (see below), and probably would be used primarily to strike large high-value targets. Given the high cost factor, such PGWs likely will remain primarily the preserve of nation-state militaries.

"Battlefield G-RAMM" include precision-guided anti-tank missiles, mortars, rockets, and artillery rounds, all with ranges of roughly 20 miles or less. Given their relatively short range, the effects of these weapons are confined

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44 Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington DC: Center for Strategic and Budgetary Assessments, 2007), pp. 14-15.

45 Michael Vickers and Robert Martinage identify it as the first of five key attributes of what they consider to be "the ongoing revolution in war." *The Revolution in War* (Washington DC: Center for Strategic and Budgetary Assessments, 2004), p. 7.

46 The Soviets also had some notable successes, e.g., the introduction of effective anti-ship cruise missiles (ASCM). The first ASCM ship-kill was achieved by the Egyptians in sinking the Israeli destroyer, INS *Eilat*, during the 1967 Six Day War.

47 Krepinevich, "Get Ready for the Democratization of Destruction."

to the "battlefield" on which they are deployed.[48] These weapons are relatively inexpensive,[49] and may be cost-effective to use against tactical targets including troops and vehicles. Although their warheads are relatively light compared to those delivered by theater G-RAMM, their precision could enable them to threaten unhardened bases and structures, staging areas, and aircraft on the ground and at altitude. One significant characteristic of these weapons is that they are relatively easy to use and maintain, even by unsophisticated forces.

If history is any guide, these PGWs will almost certainly appear in the hands of adversaries across a range of contingencies, from conventional war between state armies to irregular warfare against guerrillas or terrorist forces. Though guided weapons are seen as a "high-tech" capability, they are likely to grow more accessible to actors of modest means for several reasons. First, as more states produce these weapons and make them available through arms sales, the resulting increase in supply and competition likely will result in greater availability and lower prices. Second, since World War II, various states have routinely provided advanced weaponry to allied and client states, even to non-state proxy forces.

Thus U.S. ground forces will almost certainly have to contend with both categories of weapons in the future, but they will likely be fielded in different mixes by different adversaries. As noted above, given their high cost, "theater G-RAMMs" will mostly be fielded by nation-states, but non-state actors could potentially acquire them in small quantities or, perhaps more likely, be provided with them by a patron state.[50] "Battlefield G-RAMM," in contrast, will likely be employed by the full spectrum of adversaries, including insurgents, terrorists, and other non-state actors. Regardless of the specific mixture of long- and short-range G-RAMMs, the diffusion of these capabilities to a wide range of adversaries will force U.S. ground forces to alter significantly, perhaps dramatically, their conduct of operations.

The bottom line: A much wider range of future adversaries will increasingly be able to pose a high risk of destruction or neutralization to forces and assets formerly well beyond the effective range of their capabilities. This will likely be true at the tactical level, where adversaries will be able to employ standoff fires with far greater effect.

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[48] Use of the term "battlefield" is not intended to imply that these weapons will be used exclusively on traditional battlefields. To the contrary, their use by irregular adversaries is anticipated, as is discussed elsewhere in this assessment.

[49] The U.S. XM395 Precision-Guided Mortar Munition, for example, costs roughly $14,000 per round, according to the information contained in a recent contract award. Office of the Assistant Secretary of Defense for Public Affairs, Contracts for Tuesday, June 15, 2010.

[50] To offer one recent example of this phenomenon, Iran is believed to have provided Hezbollah with at least one anti-ship cruise missile and launch platform. The missile was fired from land and struck the Israeli corvette *Hanit* ten miles off of Beirut on July 14, 2006. It is believed to have been a Chinese C-802 (CSS-N-8 Saccade) or an Iranian-made copy of the same.

It will likely also be true at the operational level (possibly with strategic effects), with adversaries able to threaten the transport of forces, their reception, staging, onward movement and integration (RSOI) sites, and their sustainment.

3) THE PREVALENCE OF THE NON-LINEAR BATTLEFIELD

The term "non-linear" has multiple meanings in the context of land warfare.[51] Theoretical discussions of war's inherent uncertainty typically "describe systems in which causes and effects are disproportionate." In this sense, the security environment appears to be increasingly nonlinear. For the purposes of this paper, however, "non-linear" will be used in its more commonly understood sense to describe a battlefield that is different from the traditional "linear" battlefield, which has "clearly defined geometry and lines with contiguous units and deep, close and rear boundaries."[52] The Army has replaced the term "non-linear" with "non-contiguous," but significant meaning has been lost in the process.[53] Non-linearity is not merely an issue of command and control (C2) of geographically remote units. The significance of non-linearity lies in large part in the blurring of the distinction between front lines and rear areas. Ground forces have long devoted extensive thought to precise delineation and definition of specific areas of the battlefield, and adapted their doctrines accordingly as new operational concepts and technologies emerged and drove changes. For example, the Army's *AirLand Battle* was largely about subjecting the enemy's rear to attack while defending its own by synchronizing what it called the "rear, close, and deep battles," each of which was carefully specified both geographically and conceptually. The spectacularly successful ground operations in Iraq in 1991 and 2003 demonstrated U.S. ability to dominate the linear battlefield, while incurring very few casualties relative to the scale of the operations.

In practice it has been America's adversaries who have most effectively exploited the non-linear battlefield on a significant scale, particularly in Iraq and more recently in Afghanistan.

Even before these campaigns, U.S. and other theorists were heavily engaged in thinking about non-linear battlefields, with particular focus on "distributed operations," with non-contiguous units and assets of various kinds providing each other mutual and collective support in order to increase combat power while reducing vulnerability. Ironically, however, in practice it has been America's adversaries who have most effectively exploited the non-linear battlefield on a significant scale, particularly in Iraq and more recently in Afghanistan.

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[51] Phillip J. Ridderhof, "Definitions for the 'New Reality'" *Marine Corps Gazette*, June 2003, available at http://www.mca-marines.org/gazette/article/definitions-%E2%80%98new-reality%E2%80%99, accessed on November 15, 2011.

[52] *Field Manual 100-5: Operations* (Washington, DC: Headquarters, Department of the Army, 1993), pp. 6-12.

[53] The most recent (2008) edition of FM 100-5, now designated FM 3-0, "Eliminates linear and nonlinear as ways to describe the array of forces on the ground. Army doctrine now describes force arrays as occupying either contiguous or noncontiguous areas of operations." *Field Manual 3-0, Operations* (Washington, DC: Headquarters, Department of the Army, 2008), p. D-4.

U.S. forces have suffered thousands of troops killed while operating in Iraq and Afghanistan despite the absence of any linear battlefield.[54] As the Defense Science Board noted,

> Ironically, in view of much of American defense writings [sic] over the past decade, opponents have been successfully employing the concept of distributed operations.[55]

Thus in the past, when there were normally defined "front" and "rear" areas, U.S. forces typically enjoyed sanctuary in nominally "rear" areas, even when deployed far from the continental United States (CONUS) to locations such as Dhahran during Operations Desert Shield and Desert Storm, or Kuwait during the two Gulf Wars. In the future, it is highly probable adversaries will seek (and be able) to deny U.S. forces the geographic sanctuary from attack that many military planners still implicitly assume will exist.

U.S. ground operations have long been heavily supported by assets operating in one or more of the other warfare domains. This kind of support has also been mostly free from interference from enemy action. In the future, however, enemy attacks will likely not be constrained to geographic rear areas in the ground domain, but will also target other areas of operation—physical and non-physical—that have historically been safe from interference by the enemy, and thereby impact ground operations in important ways.

Critical space assets, such as satellites providing overhead reconnaissance, communications, and precision navigation and timing (PNT) data, could be neutralized or destroyed by future adversaries armed with anti-satellite (ASAT) weapons. For example, China has already demonstrated its ability to do both, having reportedly blinded U.S. reconnaissance satellites with non-kinetic means in 2006 and destroyed one of its own weather satellites with a missile in January 2007.[56] Over time these capabilities will most likely be acquired and fielded by other states.[57] Consider that a senior Russian general announced not long after

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54 Thus a large proportion of these casualties occurred among Army and Marine "rear echelon" units not principally trained, organized or equipped to engage in combat. For example, the Army estimates that one-eighth of the casualties it suffered in Iraq between 2003 and 2007 were incurred by soldiers driving or protecting fuel convoys. Steve Hargreaves, "For the military clean energy saves lives," *CNNMoney.com*, August 17, 2011.

55 Defense Science Board, *Force Protection in Urban and Unconventional Environments* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2006), p. 4.

56 Ian Easton, *The Great Game in Space: China's Evolving ASAT Weapons Program and Their Implications for Future U.S. Strategy* (Washington, DC: Project 2049 Institute, 2009), pp. 2-5.

57 India, for example, has announced plans to field its own anti-satellite weapons in the near future. Peter B. de Selding, "India Developing Means to Destroy Satellites," *SpaceNews.com*, January 4, 2010.

the Chinese ASAT demonstration that Russia "can't sit back and quietly watch others doing that; [and therefore] such work is being conducted in Russia."[58]

The reliable use of the EM spectrum is likely to be increasingly contested, with potentially severe consequences for the ability of Army and Marine Corps ground forces to have adequate situational awareness, conduct distributed operations, and bring precision fires to bear.

U.S. forces and battle networks rely heavily on the assured use of different portions of the electromagnetic (EM) spectrum for various purposes, including C2, data links, and weapons and sensors of many kinds. The reliable use of the EM spectrum is likely to be increasingly contested, with potentially severe consequences for the ability of Army and Marine Corps ground forces to have adequate situational awareness, conduct distributed operations, and bring precision fires to bear.

The same is true for U.S. forces' use of cyber space. Currently, the information flows most crucial to conducting operations are handled by the relatively secure classified SIPRNET and JWICS systems.[59] However, many crucial war fighting functions, such as logistics, remain dependent on the non-secure, unclassified NIPRNET.[60] While all networks are potentially vulnerable to cyber attacks, the NIPRNET would appear to be particularly "low-hanging fruit" for adversaries seeking to complicate U.S. operations.[61]

Cyber attack capabilities are clearly proliferating. Besides China, Russia is assessed to possess impressive computer network attack (CNA) and exploitation (CNE) capabilities, while Iran has recently boasted of its "cyber army" capabilities.[62] Such threats are not limited to states, however. Non-state actors, e.g., "cyber vigilantes," criminals, and mercenary hackers already employ significant cyber attack means for their own purposes that appear readily adaptable for attacking military targets. Then, given the difficulty of tracing many types of cyber attacks back to their source, adversaries could employ other sympathetic or mercenary parties (state and/or non-state) to attack U.S. targets while maintaining plausible deniability. Regardless of their source, hostile CNAs have the potential to shut down the information networks on which U.S. forces heavily rely and/or

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58 General Valentin Popovkin, quoted in Associated Press, "Russia building anti-satellite weapons," March 5, 2009. General Valentin Popovkin was formerly head of Russian Space Forces and now is Director of Roskosmos.

59 SIPRNET is the Secure Internet Protocol Router Network used to transmit secret-level classified information. JWICS is the Joint Worldwide Intelligence Communications System used by DoD and the Department of State to transmit top secret-level information.

60 NIPRNET is the Non-Secure Internet Protocol Router Network, the same Internet used every day by civilians. U.S. military logistics data is transmitted over NIPRNET in order to make it accessible to the many civilian enterprises involved in the supply chain.

61 Two foundational writings of Chinese military thinking, *The Science of Military Strategy* and *The Science of Campaigns* both identify logistics systems, along with C4ISR as the highest priority for cyber attacks. Bryan Krekel, *Capability of the People's Republic of China to Conduct Cyber Warfare and Computer Network Exploitation*, Report Prepared for the U.S.-China Economic and Security Review Commission (McLean, VA: Northrop Grumman, 2009), p. 11.

62 Alex Lukich, "The Iranian Cyber Army," Center for Strategic and International Studies (CSIS) Blog, July 12, 2011.

to corrupt vital data (e.g., routing information for parts and supplies needed to sustain forces in the field) required to support effective military operations.

The bottom line: Adversaries are positioning themselves to deny U.S. ground forces assured access to key domains. This includes what was formerly thought of as secure geographic rear areas in the theater of operations, other physical domains such as space, as well as access to (or use of) non-physical domains like the electromagnetic spectrum and cyber space. If not successfully countered, these efforts will almost certainly make the deployment, operations, and sustainment of U.S. ground forces far more challenging and costly enterprises than they have been in recent decades.

Future adversaries can be expected to adapt in ways that minimize U.S. advantages in precision firepower, while concurrently striving to acquire precision weapons themselves.

4) THE URBANIZATION OF WARFARE

Future adversaries, including those in the developing world, that have studied U.S. military performance over the last 60 years will reach at least one obvious conclusion: engaging the U.S. military in open terrain assures a rapid, one-sided defeat. Open battle plays to the strengths of both U.S. ground forces and the U.S. military as a whole, with the latter excelling in bringing long-range precision fires to bear on exposed enemy targets.

Future adversaries can therefore be expected to adapt in ways that minimize U.S. advantages in precision firepower, while concurrently striving to acquire precision weapons themselves. One proven way of accomplishing the former is to concentrate forces in urban areas, thereby offsetting U.S. technological advantages to a significant extent. The urban warfare environment has also traditionally required ground forces seeking to exercise control to undertake manpower-intensive operations and sustain relatively high casualties. As the Joint Urban Operations Joint Integrating Concept (JIC) notes, urban terrain

> ... tends to restrict operations by counteracting most technological advantages in range, mobility, lethality, precision, sensing and communications. This may not be true for many potential adversaries, for whom urban terrain can provide advantages, such as cover and concealment ... [Additionally, the] highly compartmented geography of urban terrain limits observation, communications, fires, and movement. Urban terrain tends to favor the defender over the attacker and the ambusher over the active patroller ... It tends to absorb higher densities of troops and other resources than other types of terrain ... [and] slows ground movement and shortens the distance of individual ground maneuvers.[63]

As a result, "urban combat operations thus tend to be bloody, episodic, and prolonged, with the costs of achieving a decision running unusually high."[64]

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[63] *Joint Urban Operations Joint Integrating Concept, Version 1.0* (Suffolk, VA: U.S. Joint Forces Command, 2007), pp. 5-6.

[64] Idem.

Potential U.S. adversaries will find this form of terrain increasingly available to them. For decades the world has been steadily undergoing a process of urbanization unlikely to cease for the foreseeable future. According to the most recent United Nations estimates, 3.5 billion people (roughly half of the world's population) presently reside in urban areas. An additional 1.5 billion people are forecast to join them over the next 20 years, increasing the proportion of the world's total population living in cities from approximately 50 percent to 60 percent. Even in what the United Nations considers "less developed countries," the urban population is expected to rise from 45 to 55 percent of the total.[65] Moreover, many of these urban areas have become conurbations of such size in area and population that they are "megacities."

The Army and Marine Corps may find themselves the central elements in urban warfare operations and campaigns, with their ability to execute this form of warfare becoming a central element of their raison d'être.

It therefore appears highly possible that U.S. ground forces will be conducting relatively more urban operations, in both conventional and irregular wars, than in the past. As suggested by the JIC, under these conditions U.S. forces will find it more difficult to exploit advantages in standoff firepower and precision fires due to target acquisition challenges, the risk of collateral damage and noncombatant casualties, and/or the need to achieve the support of the population. To the extent this environment reduces the effectiveness of air power relative to land power, the Army and Marine Corps may find themselves the central elements in urban warfare operations and campaigns, with their ability to execute this form of warfare becoming a central element of their *raison d'être*. That said, given that urban operations tend to devalue major areas of U.S. competitive advantage (e.g., ranged fires, air power, quality [vice quantity] ground combat force manpower), U.S. strategy should seek wherever possible to avoid committing American forces to such operations, relying wherever possible and as much as is feasible on ally, partner or indigenous forces.

The bottom line: U.S. ground forces will not be able simply to avoid urban combat because it is hard—they will be compelled to engage in urban combat because *it is hard. Competent adversaries will not play to U.S. strengths, but look to exploit its weaknesses. Thus, they will seek to entangle U.S. ground forces in urban fighting, and will likely find this increasingly feasible as urban areas increase in number and scale (i.e., from cities to megacities).*

5) THE PROLIFERATION OF NUCLEAR WEAPONS

Even after Cold War adversaries (the Soviet Union and China) acquired nuclear weapons, the United States enjoyed an effective nuclear monopoly over adversaries in the developing world. Its use of force in major wars in Korea and Vietnam, and in two major conflicts in Iraq was not constrained by the prospect

[65] United Nations, Department of Economic and Social Affairs, Population Division, "World Urbanization Prospects: The 2009 Revision," available at http://esa.un.org/unpd/wup/index.htm.

of confronting a nuclear-armed adversary.[66] However, since 1998 three states in the developing world have acquired nuclear weapons, and Iran is working hard to create its own nuclear arsenal. Should Iran succeed, it could trigger a "cascade" or "chain reaction" that could see Saudi Arabia, Turkey, Egypt, and possibly other states acquiring their own nuclear capability.[67]

At the same time, Russia, a "mature" nuclear power, is reportedly developing "clean" nuclear weapons with smaller yields and more precise effects that could, under certain circumstances, blur the distinction between nuclear and advanced precision-guided conventional munitions.[68] Meanwhile, these technological developments have been accompanied by a relatively public debate over the expanding circumstances—including conventional warfare—in which Russian doctrine might call for the employment of nuclear weapons.[69]

These developments suggest that the threshold at which nuclear weapons are used may change and that nuclear weapons may be perceived by adversaries as more "usable" on battlefields of the future than those of the past. This could occur because newly nuclear-armed states, likely armed with only primitive low-yield weapons and lacking the knowledge and/or inhibitions that kept the United States and the Soviet Union from using nuclear weapons during the Cold War, could actually employ them against an enemy. At the same time, mature nuclear states may choose to use tailored nuclear weapons in conventional conflicts to offset specific areas of military weakness, as the Russians are already debating.

Should the "nuclear taboo"[70] be broken, it will have major implications for how U.S. ground forces deploy, fight, and are sustained in many possible conflict scenarios, and, of course, for ground vehicle operational requirements. To date, the

The threshold at which nuclear weapons are used may change and nuclear weapons may be perceived by adversaries as more "usable" on battlefields of the future than those of the past.

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66 The United States was somewhat self-constrained in the Korean and Vietnam Wars by the prospect that escalation of either conflict could result in a nuclear confrontation with the Soviet Union. But as the U.S. approach to North Korea since its detonation of a nuclear device suggests, there is a qualitative difference between a state with nuclear weapons and a state that is merely backed by a nuclear-armed sponsor.

67 As a report to the Senate Committee on Foreign Relations noted, "An Iranian acquisition of a nuclear weapon or a nuclear weapons capability would dramatically shift the balance of power among Iran and its three most powerful neighbors—Saudi Arabia, Egypt, and Turkey. This shift in the balance of power could spark a regional nuclear arms race as Iran's neighbors seek to redress the new power imbalance." Bradley Bowman, *Chain Reaction: Avoiding a Nuclear Arms Race in the Middle East*, (Washington, DC: Government Printing Office, 2008), pp. vii-xi.

68 Office of Transnational Security Issues, *Intelligence Memorandum: Evidence of Russian Development of New Subkiloton Nuclear Warheads*, (McLean, VA: Central Intelligence Agency, 2000).

69 Mark B. Schneider, *The Nuclear Forces of the Russian Federation and the People's Republic of China,* Testimony before the Subcommittee on Strategic Forces, House Armed Services Committee, October 14, 2011.

70 According to Nina Tannenwald, "The 'nuclear taboo' refers to a powerful de facto prohibition against the first use of nuclear weapons. The taboo is not the behavior (of non-use) itself but rather the normative belief about the behavior." Nina Tannenwald, *The Nuclear Taboo: The United States and the Non-Use of Nuclear Weapons Since 1945*, (Cambridge: Cambridge University Press, 2007), p. 10.

United States has not mounted significant conventional operations against any nuclear-armed adversary, nor has the Army or Marine Corps devoted significant thought in recent years to how operations might be conducted in an environment in which the use of nuclear weapons is threatened or has already occurred.

The bottom line: The ongoing proliferation of nuclear weapons and changing attitudes about their use will substantially increase the likelihood that U.S. military forces will confront an adversary that is willing and able to employ nuclear weapons. Significantly, this is more likely than ever to occur in the developing world, where all U.S. major combat operations since World War II have occurred.

6) THE PRIORITIZATION OF FORCE PROTECTION

Force protection has become an increasingly dominant priority for the Army and Marine Corps in operations and procurement. One senior Army general has described it as nothing less than a "moral imperative."[71]

Force protection—the protection of one's own troops from harm—has usually been a priority for militaries, but one that must be balanced against others including, most importantly, mission accomplishment. In recent years, however, it has become a far higher priority for the U.S. military than ever before as measured in resources expended. Consider, as a leading indicator, the resources devoted to developing countermeasures to the IED threat in Iraq and Afghanistan—$43.5 billion for MRAP acquisition, and $20.8 billion more for the Joint IED Defeat Organization (JIEDDO).[72]

Apart from its moral aspects, the current prioritization of force protection may be, as some have suggested, at least partially the result of wavering public support for the wars in which the United States has been engaged in recent years. A study conducted during the Iraq war found that "the public forms its attitudes regarding support of the war in Iraq exactly the way one should hope they would: weighing the costs and benefits," while "the U.S. public's tolerance for the human costs of war is primarily shaped by the intersection of two crucial attitudes: beliefs about the rightness or wrongness of the war, and beliefs about a war's likely success."[73] Public support for the wars in Iraq and Afghanistan has—at

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71 Julian E. Barnes and Peter Spiegel, "Military thinks twice on fortified trucks," *Los Angeles Times*, December 27, 2007.

72 These expenses cover the period through FY 2011. See Andrew Feickert, "Mine-Resistant, Ambush Protected (MRAP) Vehicles: Background and Issues for Congress," Congressional Research Service, January 18, 2011, pp. 3-4, and Peter Cary and Nancy Youssef, "Pentagon spends billions to fight roadside bombs, with little success," *McClatchy Newspapers*, March 27, 2011.

73 Christopher Gelpi, Peter Feaver, and Jason Reifler, "Success Matters: Casualty Sensitivity and the War in Iraq," *International Security*, 30, No. 3, Winter 2005-2006, p. 8. It is worth noting that Feaver was recruited to the National Security Council in June 2005 and tasked with bolstering public support for the war. Scott Shane, "Bush's Speech on Iraq War Echoes Voice of an Analyst," *New York Times*, December 4, 2005.

different times—suffered from widespread skepticism of both the rightness and the likelihood of a successful outcome of the conflicts. With much of the American public perceiving the "benefits" of continuing to wage these wars to be low, keeping the "costs" at a tolerable level through force protection measures such as MRAPs and JIEDDO efforts was imperative for those who wished to see both efforts through to a satisfactory conclusion. General James Conway, then commandant of the Marine Corps, acknowledged as much when he told reporters in 2007 that the purpose of the MRAP program was to "save lives, [and] in the process perhaps convince the American people that we can get after this casualty thing in a real fashion and maybe buy more time on the part of our countrymen to get this thing settled."[74]

As was the case with the Korean and Vietnam Wars and more recently with the wars in Afghanistan and Iraq, public support of future conflicts may prove ephemeral, or wane sharply if they become protracted, especially if the enemy does not pose an existential threat to the United States. Yet a case can also be made that in order to generate the combat results needed for a successful campaign or war outcome, field commanders have to be willing to risk casualties, even heavy casualties, in the near-term in order to prevail more rapidly and presumably at lower overall cost. In such circumstances, the "moral imperative" of force protection clashes directly with mission accomplishment. In a sense, this was the dilemma faced by President George W. Bush in approving the dramatic increase in combat forces, along with a more aggressive engagement posture known as the "Surge" in Iraq in 2007. Fortunately the combination of increased force levels and a change in strategy, while producing more near-term casualties, resulted in a major breakthrough for the United States and its coalition partners. With success came reduced casualties, followed by a significant decline in domestic opposition to the conflict.[75]

A case can also be made that in order to generate the combat results needed for a successful campaign or war outcome, field commanders have to be willing to risk casualties, even heavy casualties, in the near-term in order to prevail more rapidly and presumably at lower overall cost.

That said, the high emphasis placed on force protection appears unlikely to be reversed, not only to satisfy a widely-felt "moral imperative" but (perhaps more significantly) also for other reasons. For example, apart from its effect on public opinion, force protection has important military value at the tactical level of warfare. For field commanders, aside from loss of life, casualties reduce the affected unit's combat power and mission effectiveness. Moreover, casualties sustained by ground forces on the move often reduce operational tempo by bringing movement to a halt while friendly forces search for attackers, secure the area, tend to wounded, and wait for medical evacuation.

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74 News Transcript, DoD News Briefing with Gen. Conway from the Pentagon, May 17, 2007.

75 Arguably, much of the domestic opposition to ongoing U.S. involvement in Iraq was for reasons other than military casualties. For one thing, casualties were far lower (both overall and on a weekly or monthly basis) than during Vietnam, the last U.S. conflict in which high casualty rates were a major source of unrest and dissent. For another, a much smaller proportion of the public has any direct connection or contact with the All-Volunteer Force (AVF) than was the case during Vietnam when U.S. forces, particularly the Army, were heavily manned by draftees.

There is also a very practical fiscal calculus behind the high priority of force protection. Casualties also represent the loss of a considerable investment in terms of the valuable equipment, training and experience they represent, plus the time and resource expenditures needed to recruit and train replacements.

This is especially significant for an all-volunteer military, as in the case of the United States. Both DoD and the American public appear satisfied with the All-Volunteer Force (AVF). Indeed, the highly professional men and women who make up the U.S. armed forces have proven to be more effective on the battlefield than the conscript forces that preceded them. At the same time, volunteers are also significantly more expensive to recruit and retain than their conscripted antecedents. In this regard every serviceman and woman constitutes a considerable investment for DoD.[76] Thus, as a news article noted in 2007, "In purely dollars and cents terms, each casualty costs the Pentagon at least $500,000, according to Lt. Col. Roy McGriff… 'This means,' he says, 'that the average unarmored vehicle with one officer and three enlisted personnel is protecting $2 million of the (Pentagon's) budget.'"[77] Moreover, since the United States has embraced the all-volunteer military, the ground forces must compete with the private sector in recruiting and retaining talent. To crudely employ a business analogy, high casualty rates represent a significant deterioration in the "work environment," making it more difficult to recruit and retain people into the armed forces. The experience of the past decade, characterized by generous pay raises, enlistment and retention bonuses, and quality-of-life enhancements for service members and their families, suggests the indirect costs of high casualty rates are substantial.[78]

The bottom line: Besides the "moral imperative," there are pragmatic reasons why force protection has become a considerably higher priority for the U.S. military than in the past. These tactical, operational, strategic, and fiscal factors will all likely compel the Army and Marine Corps to strive to maintain high levels of force protection in future conflict. At the same time the ground forces will need to avoid a "Catch-22" situation where excessive focus on force protection compromises combat power and mission effectiveness, undercutting the very reason ground combat forces are deployed in the first place. Moreover, the trends discussed earlier suggest force protection is likely to become progressively more difficult and expensive to achieve at the

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[76] Should an existential threat or national emergency necessitate conscription, the professional members of the formerly All-Volunteer Force would still constitute an invaluable source of experience and thus an investment worth protecting.

[77] Tom Vanden Brook and Peter Eisler, "Reluctance About MRAPs Costly by Many Measures," *USA Today*, July 16, 2007. Lt.Col. Roy McGriff was among the first advocates of MRAP acquisition, and wrote the Marine Expeditionary Force's Urgent Universal Needs Statement (UUNS) requesting the vehicle in 2005.

[78] For an overview of the sizeable recruitment and retention bonuses offered at the height of the Iraq War (2007), see Phillip Carter and Brad Flora, "I Want You… Badly: A Complete Guide to Uncle Sam's Recruiting Incentives," *Slate*, November 7, 2007.

desired levels. The Army and Marine Corps may find that the costs of fielding an all-volunteer force, combined with the onset of a possibly extended period of fiscal austerity, will make it difficult, if not impossible, to field forces large enough and capable enough to prevail in large-scale extended contingencies unless force protection considerations are balanced with other mission requirements.

7) THE GROWING IMPORTANCE OF PARTNERS

Since the Second World War, the United States has benefited greatly from its partnerships with foreign militaries, whether through formal alliances like the North Atlantic Treaty Organization (NATO); bilateral agreements with countries like Australia, Japan, and South Korea; or more ambiguous or contingent alignments like the partnerships with the Afghan Northern Alliance and the Sons of Iraq. Accordingly "building partner capacity" (BPC) by training and equipping partner forces in order to enhance their effectiveness is already a priority for the Department of Defense, highlighted in both the 2006 and 2010 Quadrennial Defense Reviews, and a central thrust of the U.S. approach to combating instability, especially in the developing world.

However, as its unique "unipolar moment" is brought to a close by rising challenges and reduced resources, it appears the United States may become substantially more reliant on military allies and partners than it has been in the recent past. Moreover, the need for partners to field capable ground forces may grow particularly acute, given the U.S. military's aversion to casualties, the high costs of deploying and sustaining large forces overseas, and the growing impediments (discussed in Chapter 2) to U.S. expeditionary operations posed by adversaries employing anti-access/area-denial (A2/AD)[79] capabilities designed to raise still higher the costs of projecting power.

Given its myriad interests around the world and the diverse nature of the potential threats to those interests, the United States likely will have to work with a wide range of security partners, ranging from national armies at the high end of the conflict spectrum to non-state proxies at the low end.

Given its myriad interests around the world and the diverse nature of the potential threats to those interests, the United States likely will have to work with a wide range of security partners, ranging from national armies at the high end of the conflict spectrum to non-state proxies at the low end. These partners will be characterized by varying levels of sophistication and available resources. In many cases, their forces will need to be equipped, at least in part, by the United States. However, this may pose considerable challenges for DoD. Future allies and partners may not have the financial, material, and human resources needed to operate and maintain systems as sophisticated as those typically used by the U.S. military, including ground vehicles.[80] Moreover, some partners may value

[79] Anti-access (A2) strategies employ force (and the threat of force) to prevent an adversary from entering a theater of operations and sustaining forces there (e.g. by threatening vital airfields), while area-denial (AD) strategies employ the same to deny an adversary freedom of maneuver within a theater (e.g. by threatening ships within a certain area).

[80] For example, this is a major issue in equipping the new Afghan military forces. Jack Healy, "Training Concerns Hover Over Delivery of Afghan Equipment," *New York Times*, October 18, 2011.

ground vehicle attributes very differently from the U.S. and other advanced militaries. Some may prize affordability and reliability over capability. Others may accord low priority to force protection concerns that factor prominently in recent and current U.S. vehicle procurement efforts. To put it bluntly, a million-dollar MRAP may not be the vehicle of choice for a country in which monetary resources are scarce and life is lamentably cheap. Thus the Defense Department (and the U.S. defense industrial base) will likely be challenged to provide vehicles that meet the needs and wants of many future security partners.

The U.S. military will likely become increasingly reliant on a wide range of security partners, especially those capable of fielding capable ground forces.

The bottom line: the U.S. military will likely become increasingly reliant on a wide range of security partners, especially those capable of fielding capable ground forces. Equipping these forces may prove challenging, especially with respect to partners with few resources and a technically non-proficient manpower pool. These partners may attach great importance to attributes such as affordability, ease of use, and maintainability that are not typically the top design priorities for ground vehicles produced for the U.S. Army and Marine Corps. To the extent the United States increasingly relies on allies and partners to provide a greater share of ground forces, especially in addressing irregular warfare threats in the developing world, their concerns will need to be reflected in the design of ground force vehicles.

SUMMARY

The above trends suggest that although the specific circumstances in which U.S. ground forces will be employed in the future are inherently unknowable, they almost surely will have to operate on a non-linear, highly urbanized battlefield against adaptive adversaries with some (perhaps considerable) ability to attack ground targets with precision weaponry from various ranges with effective anti-armor weapons. Some will be able to attack assets in formerly secure domains that provide critical support to ground operations. Additionally, U.S. ground forces will most likely continue to place great emphasis on maintaining a high level of force protection in conflict environments likely to be substantially more lethal than those in which they have been operating over the past four decades. As will be discussed in the next chapter, these trends will pose a number of serious challenges to how the U.S. Army and Marine Corps deploy, fight, and sustain themselves in future conflicts.

CHAPTER 2 > CHALLENGES FOR GROUND FORCES & VEHICLES

This chapter explores the potential implications of the seven key trends just described by considering the tactical, operational, and logistical challenges they likely will pose for the U.S. Army and Marine Corps. These challenges are grouped according to the ground forces' three essential tasks: deployment, combat, and sustainment.

DEPLOYMENT

Several of the trends described in Chapter 1 will almost certainly increase the ability of various adversaries to impede, or perhaps prevent, the entry and build-up by traditional means of significant U.S. ground forces in a theater of operations. This is important since, as senior U.S. military leaders are fond of saying, they prefer to "play away games." That is, they believe the United States is best defended at the source of the danger rather than waiting until it reaches American shores. It becomes more important still, given how both the Army (in particular) and Marine Corps have had to become more expeditionary since the end of the Cold War, with far fewer forces and equipment being forward-based or forward-deployed.

A Familiar Challenge

During the Cold War, plans for the defense of Central Europe against a Warsaw Pact attack required U.S. ground forces based in the CONUS to deploy rapidly to Europe where they would reinforce U.S. and allied forces based in theater. Elements of this movement were often practiced in a series of field exercises known as REFORGER (REturn of FORces to GERmany). The feasibility of rapidly deploying so large a force was predicated on a number of factors unique

to the contingency: the presence of large forward-based U.S. forces as well as other NATO forces in theater; the pre-positioning of huge stocks of supplies for CONUS-based forces to access upon arrival;[81] the priority allocation of transport ships and aircraft; high-capacity in-theater transport infrastructure (ports, roads, railroads, and airfields); and the experience and familiarity accrued from yearly trial-runs.[82] These favorable conditions made promptly deploying a large Army force to Europe a *relatively* easy task when compared to other destinations.[83] With this specific contingency foremost in mind, vehicle designers could accord lower priority to vehicle deployability when making trade-offs among various design parameters. As a result, transportability ranked 19th out of 19 in order of importance among the design requirements for the 70-ton M1 Abrams tank.[84]

In the post-Cold War security environment, deploying expeditionary ground forces to theaters other than Central Europe presented conditions the Army and its vehicle designers had not anticipated.

In the post-Cold War security environment, however, deploying expeditionary ground forces to theaters other than Central Europe presented conditions the Army and its vehicle designers had not anticipated. This was demonstrated early on by the slow deployment of U.S. ground forces to Saudi Arabia during Operation Desert Shield in the fall of 1990. The Persian Gulf was, like Germany, a place to which U.S. ground forces had prepared to go,[85] but the conditions there were less favorable for such a massive deployment.[86] The buildup of the forces for Operation Desert Storm required 163 days to complete. It may only be imagined how long the deployment would have taken had the Iraqis not been so accommodating by failing to contest the deployment of some 500,000 U.S. troops and their supplies and equipment.

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81 Thousands of vehicles (as well as other equipment and supplies) were stored in expansive warehouse complexes in West Germany awaiting use by units arriving from CONUS. This arrangement, known as POMCUS (prepositioning of material configured in unit sets), enabled the personnel of heavy units (e.g. entire armored divisions) to board military and commercial transport planes with only their personal gear, deplane in Western Europe, draw equipment and supplies from designated POMCUS stocks, and be ready to fight within days.

82 REFORGER exercises were held yearly between 1969 and 1993. REFORGER '88, which involved over 114,000 troops, was the largest maneuver conducted in Europe since World War II. U.S. Congress, Office of Technology Assessment, *Distributed Interactive Simulation of Combat* (Washington, DC: U.S. Government Printing Office, 1995), pp.24-25.

83 Of course, it would have been an enormous and incredibly complex undertaking, but it was one for which the Army was prepared, thanks to the investment, planning, and training that occurred during peacetime.

84 Steven Zaloga, *M1 Abrams Main Battle Tank 1982-1992* (Oxford: Osprey Publishing, 1993), p. 3.

85 The 1979 Iranian Revolution and Soviet invasion of Afghanistan had convinced defense planners of the need to be able to respond rapidly to aggression in Persian Gulf region. Although a Rapid Deployment Joint Task Force was established and resourced for this purpose (it became U.S. Central Command in 1983), it never loomed as large in defense planning or thinking about operational requirements as Central Europe.

86 Chiefly, forces deploying to Saudi Arabia did not enjoy the extensive infrastructure that had been built in Germany for the specific purpose of facilitating deployment.

Airborne infantrymen with negligible anti-tank capability were the only forces able to reinforce Saudi forces rapidly in the weeks immediately following the Iraqi invasion of Kuwait. The Army's heavier mechanized forces were still en route from CONUS and Germany, encumbered by their heavy vehicles and enormous logistical "tails."[87] Had the Iraqi Republic Guard "kept rolling" through Kuwait and on to Saudi Arabia, the paratroopers would have been little more than a "speed bump" in the path of Iraq's armored forces.[88]

Other conflicts in the 1990s exacerbated concerns regarding the Army's ability to deploy substantial forces rapidly. On April 3, 1999, NATO commanders decided to deploy an ad-hoc assemblage of ground forces to Albania to support Operation Allied Force against Serbia. Known as Task Force Hawk, this force included a battalion-sized mechanized force equipped with main battle tanks and infantry fighting vehicles as well as self-propelled artillery, air defense artillery, heavy engineering equipment, and other vehicles. Unfortunately, only one airfield in the area was located safely outside the range of Serbian surface-to-surface weapons, and its runway and ramp space were insufficient to accommodate the Air Force's huge C-5 Galaxy transport aircraft. The runway could accommodate smaller U.S. C-17 Globemaster transports, but was so busy accommodating the arrival of humanitarian aid that only 20 C-17s could land per day. Meanwhile, Army engineers sought to identify routes for U.S. tanks to take from Albanian ports to the Kosovo border. They concluded that weeks of route preparation by engineers (e.g., laying bridges that could support the weight of heavy tanks) would be required before even the best roads could be used. The Pentagon had publicly announced that Task Force Hawk would be deployed by April 14, but a result of these deployment obstacles, it was not ready for operations until May 7 and never fired a shot in the conflict.[89]

Exacerbating the Problem

The challenges of transitioning from a forward-deployed Cold War era force to a post-Cold War expeditionary force proved challenging to the Army (and, to a far lesser extent, the Marine Corps). The past two decades have seen a number of Army initiatives designed to enhance its ability to deploy more quickly.[90] Yet

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[87] The term "tooth to tail ratio" is often used in U.S. military parlance, where "tooth" refers to the combat arms and combat support (CS) units, while "tail" refers to the combat service support (CSS) units that provide logistical and sustainment support.

[88] Scott W. Conrad, *Moving the Force: Desert Storm and Beyond* (Washington, DC: National Defense University, 1994), pp. 28-29.

[89] John Gordon IV, Bruce Nardulli, and Walter L. Perry, "The Operational Challenges of Task Force Hawk," *Joint Forces Quarterly*, Autumn / Winter 2001-2002, pp. 52-57.

[90] The most significant for this study was the development of the Stryker family of medium-weight vehicles, which is discussed below.

the Army has been fortunate in that all of its major deployments have occurred in highly permissive environments in which the enemy has not contested the deployment of ground forces in any significant way. As the trends presented earlier suggest, however, the challenge of deploying ground forces will almost certainly become substantially more difficult.

Since World War II, any impediments to U.S. deployment of large ground combat forces have been largely due to physical factors such as difficult terrain, long distances, and lack of in-theater infrastructure. Enemies were either unable or chose not to interfere. Future adversaries who have observed the consequences of not doing so are unlikely to be as cooperative. As Indian Brigadier V.K. Nair observed in 1991, the Gulf War

> ... clearly demonstrated that a purely defensive strategy, bereft of a meaningful offensive content, especially when fighting against a modern army equipped with high technology weaponry, is self defeating. Iraq's Generals would have done well to have understood that, [as Clausewitz said] "The defense [sic] form of war is not a simple shield, but a shield made up of well directed blows."[91]

These blows might be best directed within the framework of what the Department of Defense calls an "anti-access/area denial" or "A2/AD" set of capabilities. As Nair observed following Desert Storm,

> The United States experience clearly demonstrates the dependence of extra regional forces on prepared facilities in 'host' countries ... An indirect, yet feasible method of degrading [U.S.] force application, would be to disrupt operations at these ports during the build up as also during the conflict.[92]

A2/AD capabilities are designed to make Nair's vision a reality. As its name suggests, the anti-access component of this approach seeks to prevent military forces from deploying into the region and being sustained once there. Several potential future U.S. adversaries appear to be fielding A2/AD capabilities at present, among them China and Iran.[93]

The proliferation of precision-guided weaponry is certain to make fielding anti-access forces significantly easier to achieve. Theater G-RAMMs will boost the ability of more sophisticated adversaries to attack or hold at risk the sealift

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91 V. K. Nair, *War in the Gulf: Lessons for the Third World* (New Delhi: Lancer International, 1991), p. 227.

92 Ibid., p. 180.

93 For more information on these nations' strategies and capabilities, see Andrew F. Krepinevich, *Why AirSea Battle?* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010).

ships, port facilities, large airlifters, and large airbases[94] needed to deploy and sustain ground forces on a magnitude similar to the forces deployed in the major U.S. wars since World War II. The threat to these lift assets (and their cargoes) could prevent or deter U.S. commanders from deploying major ground forces to areas where the enemy possesses theater G-RAMM capabilities, at least via readily targetable major transportation nodes such as sea and air ports of debarkation in the immediate vicinity of the threat.

Even at the "low" end of the conflict spectrum, such as in counterinsurgency operations against an irregular adversary, battlefield G-RAMM may significantly impede or even prevent the entry and buildup of forces in theater. Although battlefield G-RAMM pose less of a threat to sealift ships and port facilities—both of which can resist damage from the small warheads carried by this class of weapons—they could pose a serious threat to airlift operations. This threat could be difficult to address if battlefield G-RAMM can range an airfield from the urban areas that many airfields abut. Some battlefield G-RAMM systems, such as mortars and shoulder-fired surface-to-air missile launchers, are highly mobile and easily concealable, making them extremely difficult to locate, suppress, and eliminate in urban terrain. Traditional air base ground defense (ABGD) forces and measures will likely be challenged to protect base facilities and operations from this threat, especially in the early phases of deployment.

Traditional air base ground defense (ABGD) forces and measures will likely be challenged to protect base facilities and operations from the threat of theater and battlefield G-RAMM, especially in the early phases of deployment.

The threat to air bases from indirect fires is one that U.S. forces have largely been able to ignore for the past several decades. Indirect fires targeting bases such as Baghdad International Airport (and adjoining Camp Victory) have been infrequent, imprecise, and therefore largely ineffective against airlift operations. Veterans of Vietnam, however, recall the difficulty experienced in conducting airlift operations under indirect enemy fire at the U.S. Marine Corps' base at Khe Sanh in 1968. The North Vietnamese Army forces besieging Khe Sanh were able to mass the fire of hundreds of artillery pieces, rocket launchers, and mortars on the airfield located on the base.[95] An adversary equipped with battlefield G-RAMM could achieve the similar effects with only a handful of precision-guided systems, and could even target specific aircraft and support elements (e.g. fuel storage areas).

Although only briefly mentioned here, the challenge posed to the deployment of ground forces by nuclear weapons cannot be overestimated. Forces massed at

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[94] Heavy vehicles like tanks and infantry fighting vehicles, as well as large quantities of lighter vehicles, require large aircraft such as the C-5 Galaxy or C-17 Globemaster III to move them by air. These aircraft, in turn, require expansive airbases with long runways and large "ramp" areas for the unloading and servicing of aircraft on the ground. Such air bases are relatively rare in the developing world.

[95] Over the course of the 76-day siege, these weapons fired more than 40,000 rounds at the airstrip and the defensive positions surrounding it. Peter Brush, "The Withdrawal from Khe Sanh," *HistoryNet.com*, available at http://www.historynet.com/the-withdrawal-from-khe-sanh.htm, accessed on December 5, 2011.

ports of debarkation, bases, and in staging areas will present attractive targets for the use of nuclear weapons, should the enemy decide to escalate the conflict. For an adversary possessing relatively few nuclear weapons—like North Korea or, prospectively, Iran—and faced with the prospect of U.S. operations designed to effect regime change, the temptation to strike while and where U.S. forces are concentrated could prove irresistible.[96]

The emerging G-RAMM challenge is almost certain to raise the cost of deploying major U.S. ground forces dramatically.

THE GROWING THREATS TO EXPEDITIONARY LAND OPERATIONS

The emerging G-RAMM challenge is almost certain to raise the cost of deploying major U.S. ground forces dramatically. Consequently, future contingencies might find the historical alignment of U.S. and enemy ground forces inverted. Against an advanced adversary possessing long-range reconnaissance and strike capabilities including theater G-RAMM, the threat to air and sealift assets may be severe enough to deter—or to prevent if attempted—the deployment of large ground forces that require their use. At least initially, until the enemy's A2/AD forces can be reduced substantially, ground force deployments may be limited to light forces that can be introduced and sustained at acceptable levels of risk. Deploying large ground forces, whether heavy or light, against a less sophisticated adversary equipped with only battlefield G-RAMMs may be more feasible, although the initial costs of deployment in terms of time and losses may be significantly higher than those incurred in recent operations.

Alternatively, where feasible, U.S. ground forces could arrive in theater at secure air- and seaports of debarkation (APODs/SPODs) relatively far from the area of operations, compared with those used in the recent past. This could limit their risk to battlefield G-RAMM attacks while stressing the enemy's long-range intelligence, surveillance, and reconnaissance (ISR) assets in their attempts to identify when and where U.S. forces are arriving. Once deployed, U.S. ground forces could "march to the sound of the guns" using land transport. A road march (or movement by rail) from relatively secure debarkation points to the area of operations is unlikely to significantly tax vehicles in and of itself,[97] but it will make logistical support more demanding, an issue explored below.

In summary, even if the enemy lacks nuclear weapons, it is almost certain that the operating environment into which U.S. ground forces will be deploying will be far less permissive than in recent years. Adversaries are aware of the challenges

[96] This is not to argue that U.S. ground forces should be deployed in large numbers directly against a nuclear-armed state. The risks inherent in such a deployment are obvious. However, if such deployments were ruled out, then major U.S. ground force operations may be progressively limited to fewer and fewer contingencies.

[97] Armored vehicles can be transported on "lowboy" trailers in order to conserve fuel, minimize wear and tear to the vehicle (especially to tracks), and minimize damage to road surfaces.

of deploying large forces, and will seek to exacerbate them. At the least, future adversaries will likely be able to inflict substantial attrition of ground forces as they deploy. At worst, adversaries may be able to deny the United States use of many facilities and transport routes entirely. The systems constituting the greatest threat—theater and battlefield G-RAMMs—are highly mobile and easily concealed. They likely will be difficult to locate and destroy, even with advanced U.S. long-range reconnaissance and strike systems, prior to the entry of ground forces into theater. Air and missile strikes may suppress the threat, but U.S. and foreign experience with (unguided) RAMM suppression campaigns suggest that the forces needed to neutralize this threat are the very forces the threat is designed to prevent from deploying.[98]

THE PROBLEM OF WEIGHT

Vehicles themselves typically comprise only a fraction of the total tonnage that must be lifted into theater by air or sea when ground forces deploy.[99] However, they are among the heaviest and bulkiest individual items requiring transport. As such, they are major drivers of the need for large air transporters, like C-5s or C-17s, which require longer runways and larger ramp spaces than smaller aircraft. This in turn reduces the number of APODs able to accommodate them, thus simplifying an enemy's efforts to disrupt or prevent deployment of U.S. forces. Decreasing the size and weight of the vehicles at the larger and heavier end of the spectrum (i.e. tanks, infantry fighting vehicles (IFVs), self-propelled artillery, and engineering vehicles) would ameliorate this problem, potentially enabling the use of more airfields, smaller aircraft, and in so doing, complicating the enemy anti-deployment targeting problem.

At the same time, however, the next step "down" in size for current U.S. transport aircraft is the C-130. Although it can use a much larger number of airfields, the C-130 can only transport vehicles weighing less than 21 tons. Following the Task Force Hawk experience, the Stryker family of 8x8 wheeled vehicles was developed as a medium-weight vehicle that would fit in a C-130 but still be

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98 The U.S. and Israel found that aerial/standoff surveillance and strike were ineffective at suppressing rocket and mortar fire coming from Sadr City in 2008 and Southern Lebanon in 2006, respectively. Even ballistic and cruise missiles (which require larger launch platforms) can prove difficult to suppress, as illustrated by the United States' unsuccessful "Scud hunting" efforts during the Gulf War. William Rosenau, *Special Operations Force and Elusive Enemy Ground Targets: Lessons from Vietnam and the Persian Gulf War*, (Santa Monica, CA: RAND Corporation, 2001), pp. 33-44.

99 As Gen. Shinseki noted in 1999, "When you look at our lift requirements today, the heavy divisions' requirement for strategic lift is eighty to ninety percent in our logistical tail. It's not in the weapons platforms. Those weapons platforms count for maybe twenty percent of our lift. The rest of it is in our logistical tails." "Interview: General Eric K. Shinseki," *PBS Frontline*, available at http://www.pbs.org/ wgbh/pages/frontline/shows/future/interviews/shinseki.html, accessed on November 15, 2011.

sufficiently lethal, survivable, and mobile enough to fight effectively on the future battlefield. Strykers have proven popular with the units that have deployed with them to Iraq,[100] but as will be seen below, it is uncertain whether vehicles in this weight class can provide the required level of lethality, survivability, and force protection on the battlefield of the future.[101] Based on experiences in Iraq, it appears that medium-weight vehicles like the Stryker may be a good complement to heavy vehicles—providing some of the benefits of armored support to units that would otherwise have to do entirely without—but no substitute for them in heavy fighting. As potential U.S. adversaries are almost certainly aware, there is no easy solution to this dilemma.

COMBAT OPERATIONS

The key trends described previously are also likely to significantly alter the way U.S. ground forces fight. Several of them have already visibly manifested themselves in the first U.S. wars of the 21st century. The ongoing armor/anti-armor measure-countermeasure competition, prevalence of non-linear operations, growing urbanization, the emphasis on force protection, and the importance of allies and partners have all been important factors in U.S. ground force operations in Iraq and Afghanistan. The only trend that remains largely latent, the widespread proliferation of precision and nuclear weapons on the battlefield, has yet to occur.[102]

The Army and Marine Corps must prepare for a wide range of contingencies. Until recently these tended to be divided into the "high" and "low" ends of the conflict spectrum. At the high end, U.S. ground forces may engage the mechanized armies of other nation states—forces that look roughly similar to U.S. forces and attempt to conduct operations along "conventional" lines. This is the type of conflict for which U.S. ground forces (and their sister Services) have, since the Second World War, been best prepared and in which they excelled in 1991 and 2003. Some observers have raised concerns that the ground forces proficiency in conventional warfare has been allowed to atrophy since 2003.[103] With the draw downs in Afghanistan and Iraq, however, U.S. ground forces should be able to regain lost proficiency in traditional combined-arms mechanized operations and retain what is still a long lead over the ground forces of potential adversaries.

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[100] "M1126 Strykers in Combat: Experiences & Lessons," *Defense Industry Daily*, October 11, 2005.

[101] Current threats have already required the addition to the Stryker of slat armor to defeat rocket-propelled grenades (RPGs), and an angled "double-V" hull to better protect it against IEDs. These enhancements have added significant weight to the Stryker and compromised the strategic mobility it was initially intended to provide.

[102] While there obviously has been nuclear proliferation, U.S. forces have yet to face a nuclear-armed enemy in actual conflict.

[103] Gian P. Gentile, "The Death of the Armor Corps," *SmallWarsJournal.com*, 2010.

The "low" end of the spectrum is typified by the type of enemies with which U.S. ground forces have been engaged in irregular warfare for the past ten years. These adversaries, including the Afghan Taliban and the many different Iraqi insurgency groups, have very limited military capabilities, being deficient in training, organization, equipment, and command and control by Western military standards.[104] They have compensated for these weaknesses with other strengths, namely the fervor—sometimes suicidal—of their combatants and their ability to rely on a supportive local population—to "swim in the people as the fish swims in the sea."[105] Adapting to and overcoming the challenges posed by such adversaries has been difficult for the Army and Marine Corps, but they have been relatively fortunate to face adversaries with such limited military capabilities. Some foreign ground forces have not been so lucky, however, and their experiences may be a portent of the challenges that U.S. ground forces may face in the future.

Foreign ground forces' experiences may be a portent of the challenges that U.S. ground forces may face in the future.

The Shape of Things to Come?

In the summer of 2006, the Israeli Defense Forces (IDF) engaged the paramilitary forces of the Lebanese Islamist political party, Hezbollah, in a 34-day air, land, and sea campaign known in Israel as the Second Lebanon War. Though the IDF believed itself to be well prepared for war—it was widely regarded as one of the world's most capable militaries—and although its leaders promised a "quick and decisive" victory,[106] the war went decidedly in Hezbollah's favor. While the IDF initially hoped airstrikes and occasional raids by special forces could eliminate Hezbollah's command-and-control network and *unguided* offensive weapons, their inability to put a stop to Hezbollah rocket fire soon forced the IDF to commit substantial ground forces.[107] These forces (including heavy armor) were quickly halted by a spirited and innovative Hezbollah defense aided by numerous *guided* defensive weapons (e.g., ATGMs), with IDF units ultimately advancing only four miles north of the border and failing to secure two crucial towns.[108] When, in the final days of the war, the IDF decided to try a dash north to the Litani River—an act that some have interpreted as an attempted show of force—progress was quickly arrested and several units inserted by air were saved from imminent encirclement and possible destruction only by the UN-brokered ceasefire.[109] With the ceasefire in effect, 10,000

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[104] David E. Johnson, *Military Capabilities for Hybrid War: Insights from the Israel Defense Forces in Lebanon and Gaza*, RAND Corporation, p. 8.

[105] This metaphor was employed by Mao Zedong in 1937. Gen Samuel B. Griffith, *Mao Tse-tung on Guerilla Warfare* (Washington, DC: Headquarters, United States Marine Corps, 1989) p. 88.

[106] Matt Matthews, *We Were Caught Unprepared: The 2006 Hezbollah-Israeli War* (Fort Leavenworth: U.S. Army Combined Arms Center Combat Studies Institute Press), 2007, p. 1.

[107] Ibid., pp. 38-40.

[108] Ibid., pp. 43-50.

[109] Ibid., pp. 50-56.

IDF soldiers withdrew to Israel, having been effectively rebuffed by roughly 3,000 Hezbollah militiamen. The IDF suffered more than 120 killed and 600 wounded, while killing only 148 of the enemy in ground combat. As an advisor to the UN mission in Lebanon later observed, "In one day in 1982 [the IDF] reached Beirut; here, in six or seven days, they couldn't go more than a few miles."[110]

What had changed? It had been only six years since the IDF's last large-scale engagement with Hezbollah, yet their foe had grown considerably more formidable, combining traditional guerrilla methods with many of the sophisticated capabilities of a nation-state army. As one observer noted,

> Hezbollah, like jihadist defenders in the battles in Fallujah in Iraq … skillfully exploited the urban terrain to create ambushes and evade detection, and to build strong defensive fortifications in close proximity to noncombatants … Tactical combinations and novel applications of technology by the defenders were noteworthy. In particular, the anti-armor missile systems employed by Hezbollah … coupled with decentralized tactics were a surprise … [In one battle] a column of Israeli tanks were stopped in their tracks by Hezbollah employing Russian anti-armor missiles with telling precision. [111]

Moreover,

> Hezbollah's tactical proficiency bewildered the IDF. Hezbollah was not simply hunkering down and defending terrain, but using its small arms, mortars, rockets, and antitank weapons to successfully maneuver against the IDF.[112]

Indeed, Hezbollah proved itself capable not only of withstanding Israeli attacks, but of taking the fight to Israel in unexpected ways. Perhaps most impressively, Hezbollah was able to sustain the volume of its rocket fire despite IDF air supremacy and incursions by IDF ground forces, firing over 4,000 of its estimated 12,000 non-precision rockets into Israel over the course of the war, including a defiant last salvo of some 250 weapons in the war's final hours. Hezbollah fighters also surprised the IDF in the previously uncontested sea domain, successfully attacking an IDF corvette ten miles off Beirut with a pair of C-802 anti-ship cruise missiles (ASCM). As Hezbollah Secretary-General Hassan Nasrallah stated after the war,

> The resistance withstood the attack and fought back … it was not a regular army but was not a guerrilla in the traditional sense either. It was something in between. This is the new model.[113]

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[110] Ibid., p. 48.

[111] Frank G. Hoffman, *Conflict in the 21st Century: The Rise of Hybrid Wars* (Arlington, VA: Potomac Institute for Policy Analysis, December, 2007), p. 36. Among the anti-tank weapons used by Hezbollah were AT-13 "Saxhorn-2" and AT-14 "Spriggan" anti-tank missile launchers, which are wire-guided and laser-guided, respectively.

[112] Ibid., p. 44.

[113] Ibid., p. 22.

Military professionals around the world agreed. American analyst Frank Hoffman characterized Hezbollah's new fighting style as "hybrid" warfare, which "blend[s] the lethality of state conflict with the fanatical and protracted fervor of irregular warfare."[114] Citing the 2006 Lebanon War, he asserted,

> Hezbollah affirms an emerging trend and underscores potential dangers. Highly disciplined, well-trained, distributed cells can contest modern conventional forces with an admixture of guerrilla tactics and technology … This case offers a useful live laboratory to future antagonists who will study "how a small-scale jihadist organization managed to face down, through innovative use of guerrilla tactics and advanced weaponry, one of the strongest and most experienced conventional armies in the world."[115]

Another analyst declared the U.S. military should "expect future adversaries to go to school on the 2006 Second Lebanon War and attempt to acquire standoff fire capabilities, both direct (e.g., ATGMs, MANPADS, and shore-to-ship missiles) and indirect (e.g., rockets and mortars), that are concealable in complex terrain, particularly urban areas among civilian populations, to complicate their acquisition and attack from the air."[116]

Hezbollah does appear to offer a model or prototype for insurgent groups that wish to challenge first-rate militaries like the U.S. Army and Marine Corps. But what about "high-end" adversaries? Does the Second Lebanon War offer any insights as to how the armies of nation-states will fight? There are reasons to think it does.

Hezbollah does appear to offer a model or prototype for insurgent groups that wish to challenge first-rate militaries. But what about "high-end" adversaries?

As mentioned above, given air superiority the U.S. military has shown itself capable of defeating traditional mechanized forces employing maneuver warfare in open terrain. It may be that, as some have alleged, U.S. ground forces' "high-end" combat competencies have deteriorated since 2003. Still, it is highly doubtful that, in the foreseeable future, the armies of potential adversaries will be able to compete on anything approaching the U.S. military's competence in traditional combined arms, mechanized air-land operations. Adaptive, resourceful armies might therefore more effectively employ their manpower and material fighting in the manner of Hezbollah. In order to contest the U.S. invasion of Iraq in 2003, for example, Saddam Hussein relied relatively less on the mechanized divisions of his Republican Guard than he had in 1991, and more on die-hard Fedayeen irregular forces employing urban guerrilla tactics. It is possible to imagine the armies of developing world states adopting irregular warfare tactics

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[114] Ibid., p. 28.

[115] Ibid., p. 41.

[116] David E. Johnson, *Military Capabilities for Hybrid War: Insights from the Israel Defense Forces in Lebanon and Gaza* (Santa Monica, CA: RAND Corporation, 2010), p. 8.

similar to those employed by Hezbollah, combined with the use of urban strong points and, of course, G-RAMMs.[117]

What about *really* "low-end" adversaries? Despite the proliferation of technology, some of these will not have the means, including material and expertise, to fight on the level Hezbollah did in 2006. But even some of these non-state entities, perhaps employed covertly or otherwise as proxies by client states or antagonistic U.S. competitors, might prove capable of employing G-RAMMs to impose significant costs on U.S. and friendly forces.

Armored Fighting Vehicles In Urban Warfare

As noted above, both state and non-state adversaries will likely be incentivized to engage U.S. ground forces in urban terrain. As recent U.S. experience with urban warfare in Iraq suggests, and prior wars have demonstrated, infantry is and will likely remain king of the urban battlefield, but vehicles—though certain to be vulnerable without accompanying infantry—will remain critical enablers in urban combat.[118]

Recent U.S. experiences in Iraq, especially the heavy urban fighting in Fallujah during Operation Phantom Fury/al Fajr in 2004 and Baghdad's Sadr City during operations Striker Denial and Gold Wall in 2008, demonstrated the value of the heavy armor and firepower provided by vehicles in urban terrain, as did the IDF experiences during the Second Lebanon War and the 2008 operations in the Gaza Strip. As one Army study of the fighting in Fallujah concludes:

> A key element in the success of the coalition in Fallujah was the application of American armor, namely the M1A2 Abrams tank. The Abrams was able to take enormous punishment and continue operating … The same can be said about the Bradley vehicles, although their armor was far less capable. The Marines had dispersed their tanks to provide direct support to the riflemen, and this time-honored tactic worked to destroy systematically tough enemy positions. Conversely, the Army battalions assigned to this operation used a different approach. Instead, they led their assault with the heavy armor, which blasted through the city and unhinged the enemy

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[117] The hypothetical employment of this approach by Iran, for example, is described in Andrew F. Krepinevich's *The Conflict Environment of 2016: A Scenario-Based Approac*h (Washington, DC: Center for Strategic and Budgetary Assessments, 1996), pp. 11-16,

[118] The author of an excellent study of armor in urban fighting since World War II (using, as cases, the battles for Aachen, Hue, Beirut, Grozny, and Fallujah) concludes "there is one unshakeable principle in [armored vehicles'] employment in urban terrain. Except in the most extraordinary circumstances, tanks and armored vehicles must be closely supported by sufficient infantry or massed firepower to protect them from a wide variety of hand-held antitank weapons common on the modern battlefield." Kendall D. Gott, *Breaking the Mold: Tanks in the Cities* (Fort Leavenworth, KS: Combat Studies Institute Press, 2006), p. 114.

> defenses. This allowed for the rapid advance of the infantry and the clearing of their zone [sic] and ensured a swift victory.[119]

The same was true in Sadr City, where "heavy armor proved important in the fight, providing firepower and an ability to withstand hits from IEDs and RPGs." The need for heavy firepower in this latter engagement is illustrated by the use of the M1 Abrams' 120mm main gun and the M2 Bradley's 25mm auto-cannon. Over the course of six weeks, 818 rounds of 120mm and 12,091 rounds of 25mm ammunition were expended.[120]

The importance of heavily armored vehicles with considerable firepower may also grow as a result of the proliferation of precision weapons.

The importance of heavily armored vehicles with considerable firepower may also grow as a result of the proliferation of precision weapons. Future adversaries are likely to use battlefield G-RAMM systems such as ATGMs and precision-guided mortars to engage U.S. ground forces from longer range. Due to their precision, these weapons need not be massed in batteries or fired in salvos to achieve the desired effects. Accordingly, they will likely be employed instead by dispersed decentralized fire teams that are concealed, highly mobile or both, and capable of "shooting and scooting" from camouflaged firing positions. These firing locations may be located in urban terrain, perhaps on the outskirts of towns or along thoroughfares where sight lines are extended, and where civilian structures provide shooters with elevation, cover, and concealment while the presence of noncombatants masks their signature and impedes return fire. Adversaries may employ classic ambush tactics with interlocking fields of fire, both line-of-sight and indirect and likely in combination with mines or IEDs. Although such tactics are not novel, precision weapons will enable them to be effective from longer ranges and with smaller forces.

As one analyst has observed, the employment of *precision* weapons, which are more effective at range even if not necessarily capable of travelling any further, could

> ... expand engagement areas far beyond what irregular adversaries with lesser weapons are capable of, thus making it difficult to close with them. If precision guidance becomes available for indirect-fire weapons (e.g., rockets and mortars), the stand-off fires challenge will only become more dire and make adversary anti-access operations even more problematic. What is essentially a close combat fight of generally less than a kilometer against an irregular adversary becomes a five (or more) kilometer combined arms fire and maneuver fight to get to close combat ranges with a hybrid adversary.[121]

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[119] Kendall D. Gott, *Breaking the Mold: Tanks in the Cities*, Combat Studies Institute, 2006, pp. 105-106.

[120] David E. Johnson, M. Wade Markel, and Brian Shannon, *The 2008 Battle of Sadr City* (Santa Monica, CA: RAND Corporation, 2011), pp. 7-11.

[121] David E. Johnson, "Minding the Middle: Insights from Hezbollah and Hamas for Future Warfare," *Strategic Insights*, Vol. 10, special issues, October 2011, p. 135.

Given these considerations, maneuvering U.S. ground forces to root out enemy forces equipped with standoff weapons like guided mortars and ATGMs, and concealed in urban or other complex terrain, will be a daunting challenge.[122] Meeting the challenge will likely require new forms of fire and maneuver,[123] the success of which will likely be heavily dependent on ground combat vehicles and supporting vehicles that enable infantry to close with the enemy effectively while incurring acceptable losses of men and equipment. Vehicles carrying infantry into battle will likely require protection, whether active or passive, from potent horizontal trajectory (ATGMs), top-attack (ATGMs, guided mortars) and underbelly (mines and IEDs) threats. They will also require good off-road mobility if they are to close with the enemy across complex terrain[124] and avoid obvious chokepoints. Supporting fires may need to be both prompt and precise in order to engage low-signature, elusive targets while simultaneously packing enough high-explosive punch to destroy protective structures used by the enemy. These needs might require IFVs to be equipped with considerable organic firepower, or for tanks to accompany them in a dedicated infantry support role.

Thus, as a study of the Second Lebanon War concluded,

> Heavy forces—based on tanks and infantry fighting vehicles—are key elements of any force that will fight hybrid enemies that have a modicum of training, organization, and advanced weapons (e.g., ATGMs and MANPADS). Light and medium forces can complement heavy forces, particularly in urban and other complex terrain, but they do not provide the survivability, lethality, or mobility inherent in heavy forces. Quite simply, heavy forces reduce operational risks and minimize friendly casualties.[125]

Although urban terrain certainly will not be the only environment in which U.S. ground forces are someday compelled to fight, the foregoing considerations suggest that it will be a particularly stressful environment with unique implications for ground vehicles, and is thus worthy of the focused attention given here.

Although urban terrain certainly will not be the only environment in which U.S. ground forces are someday compelled to fight, the foregoing considerations suggest that it will be a particularly stressful environment with unique implications for ground vehicles, and is thus worthy of the focused attention given here.

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[122] The U.S. experience with rockets fired at the Baghdad Green Zone from Sadr City in 2008 also supports this observation.

[123] Fire and maneuver, which has been a mainstay of land warfare tactics for hundreds of years, requires some forces to fire at the enemy in order to suppress them and keep them from firing back, while other forces advance. Once they have reached a new position, the maneuvering forces can become the firing forces (and vice versa) allowing the entire force to advance. Combined arms tactics involve more than one "arm" of the military (e.g. armor and artillery supporting infantry).

[124] Complex terrain may be defined "as an environment in which the features of the terrain compartmentalize the units operating in it, causing them to disaggregate and greatly complicating their movement, maneuver, command and control (C2), and sustainment."

[125] David E. Johnson, *Military Capabilities for Hybrid War: Insights from the Israel Defense Forces in Lebanon and Gaza* (Santa Monica, CA: RAND Corporation, 2010), p. 8.

An Old "New Role" For AFVS?

Thus while some have predicted that main battle tanks' days were past, they appear to have found a new lease on life.[126] Indeed, heavy armor features prominently in thinking about how ground forces might conduct future urban warfare in the face of large numbers of precision weapons. Interestingly, the role they are envisioned here as playing—providing infantry support—is one that was de-emphasized during World War II in favor of a new primary mission for tanks, maneuver warfare and tank-on-tank engagements in open terrain, for which most modern tank designs are optimized.[127] Is this a paradigm shift, or does the longstanding main role of the tank and other AFVs still remain of relatively greater importance than the support it can provide to infantry?

Heavy armor features prominently in thinking about how ground forces might conduct future urban warfare in the face of large numbers of precision weapons.

Several trends appear likely to undermine the importance of the tank's traditional role in maneuver warfare. The increasing prevalence of non-linear warfare suggests future adversaries are unlikely to have well-defined rear areas that can be penetrated or lines of supply and communication easily severable by armored forces. Moreover, the growth of urban terrain and its likely exploitation by future adversaries may limit the opportunities for armor to effect deep penetrations along the lines of what occurred in Europe during World War II and the later Arab-Israeli wars.[128] If the proposition that future land warfare is more likely to involve significantly greater amounts of urban or urbanized terrain (either because that's where the objectives or "prizes" of the conflicts are likely to be located, or because enemy forces choose to concentrate there and cannot easily be bypassed), then AFVs may prove useful in encircling and isolating enemy forces into urban areas, but likely only as a prelude to a prolonged "siege" and/or slow block-by-block clearing operations rather than a rapid victory. To employ a historical analogy, future armored combat may increasingly resemble the Battle of Stalingrad more than the Blitzkrieg of France and the Low Countries.

The tank's role in countering enemy armor may also decline in significance. As noted above, U.S. adversaries are unlikely to be so foolish as to engage U.S. ground forces in combined arms mechanized maneuver warfare, though a number of potential adversaries are investing considerable resources in maintaining or expanding their armored forces (though not necessarily with the United States

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[126] The "death of the tank" has been heralded at several points since World War II including, most recently, following the end of the Cold War. LTC John Craddock, *The Tank Is Dead—Long Live the Tank*, (Carlisle, PA: U.S. Army War College, 1993).

[127] Gott, *Breaking the Mold*, p. x.

[128] The 1991 and 2003 offensives against Iraq are of course examples of relatively traditional maneuver warfare, but the nature of these operations arguably reflect a somewhat unique combination of ideal terrain for armored thrusts and a very incompetent enemy.

in mind as their primary potential enemy).[129] The anti-tank capabilities of U.S. armor are undoubtedly a major factor in deterring rivals from engaging in a direct fight with U.S. ground forces—but only one of several. U.S. air power has also proven extremely effective against enemy mechanized forces in both wars against Iraq and, more recently, against the forces of Muammar Gaddafi's collapsing regime. Even light U.S. infantry units have demonstrated their ability to defeat enemy armor when equipped with battlefield G-RAMM. At Debecka Pass in Northern Iraq, for example, two U.S. Special Forces "A-Teams" equipped with shoulder-fired FGM-148 Javelin anti-tank guided missiles held off an attack by a company-sized Iraqi mechanized force, destroying two tanks, eight armored personnel carriers, and compelling the remaining forces to retreat after a four-and-a-half hour battle. Similarly equipped forces of light, highly mobile infantry may alone—or, better yet, in cooperation with air support—be sufficient to block the advance of enemy armor in some circumstances.

How then might the rediscovered importance of infantry support and a potential decline in the importance of the traditional anti-tank role manifest itself in the design of AFVs? There may be a historical and perhaps ironic precedent in the "infantry tank" concept, which was developed in Britain and France between the World Wars but fell out of favor during the Second World War. These tanks traded speed for protection, provided by heavy armor, and mounted large-caliber, lower-velocity guns suited to firing high-explosive rounds. Such a shift in paradigm could allow vehicle designers to relax the speed requirements of future tanks—and the IFVs that are expected to keep up with them—thereby freeing up "trade space" which could be used to improve protection, transport capacity, fuel efficiency, or affordability. This is not to suggest that such a change is necessarily in order, but rather that it is worth exploring as changes in the security environment threaten to undermine long held notions about the role of heavy armor.

Survivability, Mobility, And Tactical Wheeled Vehicles

While the seven trends described above will pose substantial challenges for combat vehicles designed to withstand the rigors of battle, their implications may be more profound for tactical wheeled vehicles (TWVs). These vehicles are comprised of trucks and utility vehicles (including the Humvee) that provide transport and other crucial combat support services. They are designed to do so in

[129] China and Russia continue to modernize their armored forces and to train in combined arms mechanized warfare. Russia, for example, intends to build a 500-square kilometer training center designed to host exercises by brigade-sized armored and mechanized units, not unlike the U.S. Army's National Training Center at Fort Irwin. Albrecht Mueller, "Rheinmetall To Sell Training Facility To Russia," *DefenseNews*, November 25, 2011. Venezuela, meanwhile has announced ambitious plans to significantly enhance its modest armored forces, and has already taken delivery of a number of modern tanks from Russia. Agence France-Press, "Venezuela's Chavez Thanks Russia for Tanks," August 17, 2011.

relatively secure areas. As in the case of the Humvee, these vehicles were not designed for combat. Unfortunately for the ground forces, the non-linear battlefields of Iraq and Afghanistan have seen these vehicles regularly exposed to enemy attack. In response, the Army and Marine Corps have gone to great lengths to improve the survivability of existing TWVs—generally by "bolting-on" plates of supplemental armor—while replacing other vehicles (such as many Humvees) with members of the MRAP "family of vehicles."

These measures have improved the survivability of TWVs and their occupants, but they have drawbacks. Perhaps most importantly, the addition of significantly more armor to TWVs, whether bolted-on to existing vehicles or designed into new vehicles like MRAPs, has adversely impacted the mobility of individual TWVs and the overall fleet. The imposition of significantly more weight on chassis not designed to accommodate it has hurt automotive and off-road performance of up-armored vehicles, while new MRAPs, with their high ground pressure[130] and high centers of gravity (which make them susceptible to rolling over), have in several cases proven incapable of effective cross-country movement. Unable to leave the road, these vehicles must travel along relatively predictable routes and are therefore more susceptible to ambush. Additionally, both up-armored vehicles and MRAPs have proven generally more prone to mechanical breakdowns. Technical means of ameliorating these issues have been identified and applied to existing vehicles, but typically at substantial cost.[131] Meanwhile, efforts to develop a new Joint Light Tactical Vehicle that provides the protection of an MRAP while maintaining the mobility of a Humvee have thus far been unable to meet both objectives at an affordable price. The general trend, therefore, clearly suggests that there is a tradeoff between survivability and tactical mobility.[132] This tradeoff will grow more acute if, as forecast here, the future operating environment grows more lethal while force protection remains a priority. TWVs can ill afford to trade away mobility since mobility (mostly used for personnel and cargo transport) is the principal benefit these vehicles provide. Additionally, ground mobility may grow even more important if the general proliferation of battlefield G-RAMM places sophisticated surface-to-air missiles in the hands of future adversaries. The possession of such weapons by the enemy would seriously impact the ground forces' ability to move men and materiel by helicopter (as the Soviet

The tradeoff between survivability and tactical mobility will grow more acute if the future operating environment grows more lethal while force protection remains a priority.

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[130] Ground pressure is the pressure exerted by a vehicle on the ground, a function of the total weight of the vehicle and the total area in which the vehicle is in contact with the ground. Tracked vehicles distribute their weight over the large rectangular areas of their treads, while the weight of wheeled vehicles is concentrated in the much smaller total area where their tires come in contact with the ground.

[131] For example, the Marines have spent $160,000 per vehicle improving the suspension systems of some MRAPs in order to improve their off-road mobility in Afghan terrain. Scott Calvert, "Aberdeen Tests Military's Cougar," *Baltimore Sun*, July 12, 2009.

[132] Of course, increased weight of TWVs also adversely impacts their inter-theater mobility, or deployability, in the manner discussed above.

Army experienced in Afghanistan). Already costly, air mobility could become prohibitively expensive in such an environment, making the intra-theater ground mobility provided by TWVs all the more important.

Lastly, it is worth noting that tactical mobility provides a degree of protection in and of itself. The ability to move at relatively high speeds across all terrain enables vehicles to avoid concentrations of enemy strength and being channelized into predictable ambush points. This being the case, tactical wheeled vehicles may best be protected by a combination of some retained mobility and scalable, modular armor options that can be rapidly fielded—and removed in more benign environments or when greater mobility is needed. In order to accommodate these modular options, said vehicles will need to be adaptable, as will be discussed in Chapter 3, with the capacity (in terms of surplus space, weight, and power, or "SWaP") to integrate them. Finally, as non-armor protection measures such as passive countermeasures (e.g. jammers) and active protection systems develop, they may provide a *partial* substitute for additional armor that weighs less and has less impact upon mobility. Given the diverse array of anti-armor threats envisioned here, as well as the rapid rate at which they are expected to evolve, however, it seems unlikely that these systems will be able to provide comprehensive or lasting protection. This being the case, some ability to "take hits and keep going" will remain an essential attribute.

Technological solutions by themselves are unlikely to allow vehicles to keep pace with evolving threats—at least not affordably.

The Armor/Anti-Armor Competition And Cost Imposition

Ultimately, however, technological solutions by themselves are unlikely to allow vehicles to keep pace with evolving threats—at least not affordably. As analysts at RAND have observed regarding vehicle protection, "technology-based solutions to mitigate vulnerability are expensive, whereas the enemy's countermeasures are relatively cheap."[133] It therefore appears likely that the dynamic armor/anti-armor competition forecast here will impose tremendous costs on the United States should it strive to keep up with technical means. Even if, as seems likely, adversaries acquire battlefield G-RAMM with anti-armor capabilities, their cost will likely be only a fraction of the costs they impose on the U.S. military in terms of countering them.

This does not mean, however, that new vehicle protection measures are not worth fielding. As noted above, there are pragmatic as well as moral reasons behind the prioritization of force protection, and the costs of *not* adopting new measures to counter emerging threats, and taking additional losses as a result, must always be kept in mind. That said, given prospective resource constraints and the dynamic nature of the competition, it makes little sense for the ground forces

[133] *The U.S. Combat and Tactical Wheeled Vehicle Fleets: Issues and Suggestions for Congress*, RAND Corporation, 2011, p. 123.

to continue to adopt expensive protection measures that will likely be quickly and relatively inexpensively countered. Instead, U.S. designers should emphasize vehicle protection measures—both technical[134] and operational[135]—that can be applied quickly and affordably to the existing vehicle fleet. Moreover, U.S. strategy should place priority on leveraging the use of indigenous and allied forces in ground combat operations where possible, rather than U.S. troops. Finally, scarce science and technology (S&T) funding should be used to explore vehicle protection technologies that could credibly deliver truly revolutionary payoffs, as opposed to only marginal improvements in survivability that may be easily countered, and in protective measures that are relatively cheap compared to the costs they impose on the enemy.

Time To Revisit The Nuclear Battlefield

It is worth briefly noting, again, the challenges that could be posed by a nuclear-armed adversary. As discussed in Chapter 1, while the United States considers the use of nuclear weapons to constitute a major escalation in warfare, future adversaries, including emerging nuclear powers, may not feel the same way. If coupled with a willingness to use them, possession of even a small number of nuclear weapons by the enemy will pose tremendous risk to ground forces, especially when these forces must concentrate to conduct operations.[136] Accordingly, ground forces under threat of nuclear attack will need to minimize their attractiveness as targets for nuclear weapons and to mitigate the effects of being attacked.

Ground forces under threat of nuclear attack will need to minimize their attractiveness as targets for nuclear weapons and to mitigate the effects of being attacked.

Moreover, it is important to consider operations not only in an environment in which nuclear weapons might be used, but also in an environment in which nuclear weapons are being or have already been used. Had a conventional war between the United States and the Soviet Union escalated to a nuclear exchange, the catastrophic destruction wrought by the employment of so many and such powerful weapons would likely have rendered the conduct of further conventional operations irrelevant. In a conflict with prospective future nuclear adversaries possessing a far smaller number of weapons (e.g. North Korea or, potentially, Iran), by contrast, nuclear use may not lead to Armageddon. Given these

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[134] There are some low-cost countermeasures that have not found the U.S. military on the wrong side of the cost competition. An example is the RPG nets developed by DARPA. These simple nets are designed to hang on the sides of vehicles and "trap" incoming anti-tank rockets, crushing their noses and preventing the formation of the shaped charge plasma jet that could penetrate the vehicle armor. In so doing, they greatly undermine the effectiveness of weapons like the RPG-7 anti-tank rocket launcher, a weapon possessed by many potential adversaries.

[135] Examples of operational options can include urban siege operations rather than urban eviction operations, and conducting phased operations that delay the deployment of major ground forces until the enemy's G-RAMM and anti-armor capabilities have been significantly eroded.

[136] A fundamental tradeoff in a nuclear operating environment is between minimizing overall vulnerability via dispersal versus mass forces in order to concentrate combat power.

considerations, should such an adversary employ nuclear weapons, U.S. forces may still have to operate in a nuclear environment, protecting themselves from radiation while conducting operations to achieve their objectives (e.g., defeating enemy forces; conducting disaster relief; etc.).

More detailed thinking about the nuclear battlefield lies beyond the scope of this study. This report can only briefly note the increasing potential for nuclear weapons being employed on the battlefield if present nuclear proliferation trends continue, and suggest that the implications for ground vehicle requirements are therefore worthy of greater consideration than they have been since the Cold War.

SUSTAINMENT

Like deployment, sustainment[137] is a complex and challenging undertaking even without enemy interference. The same trends increasingly challenging U.S. ground forces in deploying and operating will affect future sustainment activities in many contingencies.

Of the trends apart from G-RAMM proliferation, the growing prevalence of non-linear warfare will likely have the greatest implications for U.S. ground force sustainment.

Logistics Under Fire

Of the trends apart from G-RAMM proliferation, the growing prevalence of non-linear warfare will likely have the greatest implications for U.S. ground force sustainment. Logistics has historically been a "rear area" undertaking performed in relative safety behind the front lines, away from the field of battle. With the advent of air forces, rear areas became increasingly vulnerable to attack. U.S. ground forces, however, have been fortunate in that U.S. air power has generally enjoyed air supremacy over every area where land forces have been deployed since the early days of U.S. operations in World War II. In a conflict without front lines, however, U.S. CSS units will likely have to carry out their duties under threat of enemy attack. As the Defense Science Board has observed, "When there are no front lines, all forces are at risk and logistic convoys, like merchant ship convoys in World War II, become 'movements to contact,' or are targets for loosely organized enemy actions."[138] Moreover, as battlefield G-RAMMs proliferate and enemy forces more often seek protection in complex terrain, air superiority will likely count for less since it may be relatively less effective in suppressing such weapons.

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[137] The Department of Defense defines sustainment as "the provision of logistics and personnel services required to maintain and prolong operations until successful mission accomplishment." *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms*, as amended through 15 October 2011. Sustainment activities include supply, maintenance, transport, and healthcare, among other essential services.

[138] Defense Science Board, *Force Protection in Urban and Unconventional Environments*, p. 4.

Indeed, protecting supply convoys has proven extremely challenging in both Iraq and Afghanistan, where insurgents have deliberately targeted logistical support (and fuel supplies in particular) due to its critical importance and the relative vulnerability of assets engaged in such operations. Although these attacks have not seriously disrupted the flow of fuel or other critical supplies, they have necessitated extensive convoy security measures, with a typical 16-truck supply convoy in Iraq protected by four MRAPs, roughly a platoon's worth of riflemen (in addition to truck crewmen), and two Apache helicopter gunships overhead.[139] Such attacks have also exacted a considerable human toll. The Army estimates 3,000 soldiers were killed or wounded while driving or protecting fuel convoys in Iraq between 2003 and 2007, roughly one-eighth of total U.S. casualties during that period.[140] According to a 2009 study by the Army Environmental Policy Institute that appears to be based on the same data, casualty rates for fuel convoys in Iraq and Afghanistan were .026 and .042, respectively. This translates into one casualty for approximately every 38 convoys in Iraq, and every 24 in Afghanistan.[141]

As these numbers indicate, the business of sustaining U.S. ground forces is already a very dangerous one. Unfortunately for the ground forces, the challenge of sustaining ground forces in a non-linear combat environment will likely be exacerbated by several of the other trends. The proliferation of battlefield G-RAMMs is perhaps most worrisome, as this will provide even unsophisticated or unskilled adversaries the means to attack logistics convoys effectively from greater ranges than at present. This, in turn, may require still more forces and assets to be dedicated to convoy protection.

The possession by the enemy of G-RAMM will also increase the threat to other links in the ground forces' logistics chain besides convoys. Most supplies arrive via the same means and routes (transport ships and aircraft, APODS and SPODS, large depots and staging bases) as the deployed forces being supported. Thus the threats to deployment operations described above also pertain to sustainment operations. Accordingly, if the ability of future G-RAMM-equipped adversaries to threaten, impede, or destroy the assets required to move materiel into the theater cannot be degraded in the early stages of a conflict it could seriously disrupt the supply chain and impede sustainment. This risk may be posed not only by relatively sophisticated adversaries with theater G-RAMM, but also by irregular opponents with battlefield G-RAMM. These weapons could be used to attack transport aircraft, airbase operations, and fuel and supply stockpiles, all

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[139] Army Environmental Policy Institute, *Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys - Final Technical Report*, September 2009, p. A-1.

[140] Steve Hargreaves, "Ambushes prompt military to cut energy use," CNNMoney, August 16, 2011; and "The true cost of the military's addiction to oil," graphic, available at: http://money.cnn.com/technology/storysupplement/cost_military_oil_addiction/. Accessed on January 30, 2012.

[141] Army Environmental Policy Institute, *Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys - Final Technical Report*, September 2009, p. i.

of which have been relatively secure in recent conflicts behind base perimeters. Here, again, the specter of Khe Sanh contrasts sharply with the more recent experience of Camp Victory.[142]

Further compounding the threats to the steady flow of supplies, future adversaries' attempts to interrupt sustainment activities may not be confined to the physical realm. In addition to the supply dumps and depots where arriving materiel is stored and the personnel and vehicles that move it forward are located, logistics on the scale involved in major ground combat operations requires a high level of coordination. As discussed in Chapter 1, much of that coordination is currently achieved with computer networks—many of them unclassified and linked to non-military networks. Such networks are highly susceptible to interruption and manipulation. If adversaries were to interrupt this flow of information about what is needed, what is available, and where—or perhaps corrupt the data so as to create doubt about its accuracy—it could seriously hinder the flow of critical supplies.

While the logistics demands of ground vehicles are manifold, fuel is by far their greatest need.

Implications For Ground Vehicles

If logistics vehicles are to defend themselves in convoy operations on what is likely to be a non-linear and increasingly lethal battlefield, they will need to be armed and armored. Escort forces operating in combat vehicles or more combat-worthy TWVs (e.g. MRAPs) can certainly aid in the defense of these convoys (as can aircraft), but reliance on these assets for protection reduces their availability for other missions. To the extent these other missions must be supported by additional combat vehicles and aircraft, it increases the need for additional logistics support, requiring still more convoys and creating a vicious circle. The ground forces have taken significant steps to improve the survivability of logistics vehicles (better protecting their crew and passengers, if not their payloads), but additional steps may be required as threats evolve.

Obviously these sustainment challenges have implications for all ground vehicles since all require some form of logistics support. Generally speaking, while the logistics demands of ground vehicles are manifold, fuel is by far their greatest need.[143] Fuel accounts for fully 70 percent of the bulk tonnage of

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[142] It is worth noting that U.S. strength at Khe Sanh peaked at five battalions, which required approximately 185 tons of supplies per day. One modern airborne brigade combat team—the lightest standalone unit in service—requires 300 tons per day while engaged in heavy combat, according to Robert W. Button, John Gordon IV, Jessie Riposo, Irv Blickstein, and Peter A. Wilson, *Warfighting and Logistic Support of Joint Forces from the Joint Sea Base* (Santa Monica, CA: RAND Corporation, 2007), pp. 83-84.

[143] U.S. military vehicles run on Jet Propulsion No. 8 (JP-8), a kerosene-based fuel that is also used by aircraft and generators. Use of a single fuel greatly simplifies logistics.

materiel that the ground forces must transport to the battlefield.[144] According to both the Army[145] and Marine Corps,[146] ground vehicles are responsible for roughly a third of their fuel demand in theater (32 and 30 percent, respectively), the other major contributors being aircraft and electrical power generators. Heavy combat vehicles are the biggest individual consumers—the M1 Abrams tank, for example, is powered by a turbine engine that burns two gallons of fuel per mile driven (i.e., gallons *per mile*, and not vice versa) and 10-12 gallons per hour while idle with its engine running.[147] Tactical wheeled vehicles, which are less inefficient but far more numerous, consume more fuel overall. Humvees, medium trucks, line haul trucks (which are themselves hauling fuel 70 percent of the time) and heavy equipment transporters are the leading aggregate consumers of fuel among ground vehicles.[148]

As a result of these consumption rates, the Defense Science Board found that "operations suffer from unnecessarily high, and growing, battlespace fuel demand which degrades capability, increases force balance problems, exposes support operations to greater risk than necessary, and increases life-cycle operations and support costs."[149] Given the trends described above, these problems appear likely to worsen over time. If the challenges of sustaining U.S. ground forces are exacerbated as forecast here, minimizing their logistical demand will likely become even more of an imperative than it is at present. This being the case, fuel efficiency appears likely to be an increasingly attractive quality in ground vehicles.

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144 "Q&A: Dr. Grace Bochenek – Director, U.S. Army Tank Automotive Research, Development and Engineering Center," CALSTART.org, available online at: http://www.calstart.org/projects/hybrid-truck-users-forum/htuf-blog/10-09 21/Q_A_Dr_Grace_Bochenek_%E2%80%93_director_U_S_Army_Tank_Automotive_Research_Development_and_Engineering_Center.aspx; and Alan E. Haggerty, "S&T and Maneuver Warfare: A Current Success and a Future Challenge," PowerPoint briefing, July 29, 2008, available online at: http://www.dtic.mil/ndia/2008maneuver/Haggerty.pdf. Accessed on January 30, 2012.

145 According to the Defense Science Board, at a "wartime OPTEMPO" (operational tempo), combat vehicles consume 162 million gallons (15.5 percent) and tactical vehicles consume 173 (16.6 percent). Army aircraft consume 307 million gallons (29.2 percent), while generators create the greatest demand: 357 million gallons (34 percent). *Report of the Defense Science Board Task Force on DoD Energy Strategy: More Fight—Less Fuel*, (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Logistics, and Technology, 2008), p. 44.

146 Gayle von Eckartsberg, "USMC Expeditionary Energy: 'Bases to Battlefield,'" PowerPoint presentation, MCB Camp Lejeune, November 2011.

147 Bruce Gudmundsson, *On Armor* (Westport, CT: Praeger, 2004), p. 175.

148 Amory Lovins et al., *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security*, (Snowmass, CO: Rocky Mountain Institute, 2005), p. 87.

149 Defense Science Board, *More Fight—Less Fuel*, p. 3.

SUMMARY

This chapter finds that both alone and in combination, the seven trends described in Chapter 1 appear likely to pose substantial challenges for U.S. ground forces as they undertake to deploy, fight, and sustain themselves in future conflicts. Two central themes emerge from this assessment. First, the operating environments for ground forces are almost certain to be far less permissive than those to which U.S. ground forces have grown accustomed over the past two decades. Second, adapting effectively to the less permissive environment in an era of fiscal austerity will require very difficult trade-offs in the management of the Army and Marine Corps ground vehicle portfolios and in the design and procurement of the next generation of vehicles. Failure to do so could find the U.S. ground forces literally pricing themselves out of the mission of projecting and sustaining decisive ground combat power in major contingencies.

CHAPTER 3 > **THE WAY AHEAD**

The challenges described in the previous chapter are not new in the sense that the U.S. military's ability to project power has been seriously contested before, (e.g., in the European and Pacific Theaters of Operation during World War II). However, what may be new is that the cost of deploying, operating, and sustaining large ground forces in the kinds of future operating environments described earlier may be far higher—both in terms of vehicle life-cycle costs and combat losses of personnel and materiel—than has been the case in recent decades. Absent substantial changes in the way the Army and Marine Corps deploy, operate, and sustain their forces; and how they design and field the types of vehicles and other equipment that will be survivable and effective on future battlefields, the two Services may find their ability to conduct major ground operations at acceptable levels of cost and risk called into question.

Acquiring vehicles with suitable characteristics is a potentially expensive proposition. Yet U.S. defense spending is likely to decline substantially for the foreseeable future. These prospective resource constraints make it imperative that the Army and Marine Corps spend their scarce resources wisely.

This chapter will describe several broad factors force planners and vehicle designers should take into consideration as they seek to "round the square," that is, to develop and field the appropriate vehicles to support the ground warfare operating concepts needed to address the future operational challenges and key trends discussed earlier while facing potentially severe budgetary constraints.[150]

Prospective resource constraints make it imperative that the Army and Marine Corps spend their scarce resources wisely.

[150] Readers tempted to easily dismiss this proposition as "merely doing more with less" should remember that the interwar period, also a time of rapid technological change and severe budgetary constraints, saw development of radically new and different military capabilities and concepts of operation, including combined-arms mechanized warfare, carrier aviation, and long-range strategic bombardment.

These include:

> Conserving scarce resources;

> Maximizing adaptability;

> Exploring key technologies; and

> Protecting the defense industrial base.

CONSERVING SCARCE RESOURCES

Given projected budget cuts, defense planners and vehicle designers should operate under conservative assumptions regarding the resources available for modernization and the willingness of senior defense policy makers to tolerate production delays and cost overruns. Based on the strategic guidance set forth by the Obama administration in January 2012, the Pentagon is operating under the assumption that cuts to defense spending will be limited to the $487 billion over ten years called for in the bipartisan Budget Control Act of 2011. This assumption may well prove optimistic. It would be prudent for the Army and Marine Corps to hedge against the likelihood that substantial additional cuts will be forthcoming.

Perhaps most ominously, the failure of the so-called congressional "Super Committee"[151] to agree on the steps to cut at least $1.2 trillion from the federal deficit over the next decade has triggered a fallback agreement requiring the sequestration of funds from the Federal budget's discretionary spending accounts. Those funds would be divided evenly between domestic discretionary spending and national security spending.[152] If sequestration were implemented, and military personnel accounts are exempted as the law allows, it would reduce Army and Marine Corps modernization funding over the next five fiscal years by roughly 25 percent. The impact of the cuts would not begin until FY2013, when procurement and R&D funding could be 23 percent lower than what was planned in the most recent Future Years Defense Program. Cuts would reach nearly 26 percent by FY2016.[153]

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[151] Formally, the Joint Select Committee on Deficit Reduction, or JSCDR.

[152] Sequestration requires the Office of Management and Budget (OMB) to cut the federal budget by $1.2 trillion over the period covering FY 2013-2021. Since some of the $1.2 trillion will be covered by reduced interest (as less debt will be incurred), this amount is reduced to $984 billion. The cuts must be evenly apportioned over the nine years, resulting in an annual cut of $109 billion. This cut is evenly divided between domestic discretionary spending and national defense spending, producing cuts of about $55 billion per year for national defense. Todd Harrison, *Defense Funding in the Budget Control Act of 2011* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011), p. 3.

[153] These figures are all based on the assumption that the reductions under both the initial cuts specified in the Budget Control Act and under sequestration are applied to the Department of Defense's topline proportionately with the other funding lines included under the same budget caps. It further assumes that within the DoD budget 50 percent of the cuts come from procurement and RDT&E (research, development, testing, and evaluation) funding, even though these funding lines only comprise 33 percent of the budget, and that the each of the Services are cut by an equal percentage.

FIGURE 1. POTENTIAL DECREASES IN ARMY AND MARINE CORPS MODERNIZATION FUNDING[154]

Size of Total Defense Cuts	Impact on Modernization Funding relative to FY2011 FYDP levels				
	FY12	FY13	FY14	FY15	FY16
$487 billion	-7.5%	-12.2%	-13.5%	-13.7%	-13.9%
$1.2 trillion	-14.4%	-23.0%	-25.1%	-25.6%	-25.9%

Sequestration may ultimately be avoided, but an alternative to sequestration, if one can be reached, will likely require significant spending cuts, to include cuts to the defense budget. It is worth noting that even in the best case, in which cuts are limited to $487 billion, cuts to Army and Marine Corps modernization accounts could still be significant: approximately 12.2 percent in FY2013, rising to 13.9 percent in FY2016.[155]

In light of these prospective fiscal pressures, the military Services should expect that senior defense policy makers will have far lower tolerance for production delays and cost over-runs in acquisition programs than has historically been the case. As former Defense Secretary Robert Gates noted, in this "age of austerity," the Defense Department can ill-afford to support programs based on overly ambitious or unrealistic assumptions regarding the maturity of key enabling technologies, program costs, or development timelines.[156] Secretary Gates underlined this in no uncertain terms in April 2009 and January 2011, when he terminated the Army Future Combat System (FCS) and Marine Corps Expeditionary Fighting Vehicle (EFV) programs on exactly these grounds. Given the prevailing circumstances, neither the Army nor the Marine Corps can afford to continue

Military Services should expect that senior defense policy makers will have far lower tolerance for production delays and cost over-runs in acquisition programs than has historically been the case.

[154] See assumptions, above.

[155] See assumptions, above.

[156] Robert M. Gates, Defense Budget Recommendation Statement, Arlington, VA, April 6, 2009.

pursuing the kind of acquisition strategies the Pentagon has been pursuing.[157] The results have seen the ground forces extend the service lives of existing systems and acquire off-the-shelf solutions, but only after expending vast amounts of time and money on overly ambitious programs that failed to meet their development timelines. An acquisition strategy better suited to the current and prospective fiscal environment might be to invert these preferred and fallback courses of action: extending service lives and acquiring off-the-shelf solutions whenever possible, and undertaking ambitious developmental efforts only when absolutely necessary, or when there is a *realistic* expectation of a revolutionary leap in system performance.

In accordance with this strategy, defense planners should as a general matter employ a philosophy of "use it up, wear it out, make it do, or do without" whenever possible by:

Defense planners should seek to "use it up, wear it out, make it do, or do without" whenever possible.

> EXTENDING THE SERVICE LIVES OF EXISTING SYSTEMS. The Army and Marine Corps should extend as long as economically possible the service lives of existing vehicles, particularly those deemed relatively well-suited to the future operating environment described earlier in this report. Efforts also should be made to determine whether vehicles that appear likely to be increasingly unsuited for future missions could be modified to perform other useful missions effectively. As the long history of the M113 armored personnel carrier suggests, some vehicles could enjoy long and useful "second lives" if retained in other roles.

> SEEKING OFF-THE-SHELF (OTS) SOLUTIONS. Acquiring OTS or modified/adapted OTS designs could generate substantial savings by obviating the need for new engineering and manufacturing development, and by leveraging the

[157] Part of an acquisition strategy is also how you contract to perform the work. The way the Army contracted for FCS represents a poster child for how not to do procurement. Indeed, the contract the Army negotiated was in itself a major reason the program failed. They used a Lead Systems Integrator (LSI), which effectively outsourced much of the government's role in defining requirements and managing the program. To make things worse, they negotiated a cost-reimbursable contract for the LSI with a 7.5 percent fixed fee and an additional incentive fee of 7.5 percent. Thus, no matter how poorly the program performed the LSI was guaranteed to make a 7.5 percent profit. Moreover, the award of the additional 7.5 percent incentive fee was based on the successful completion of program events, not program outcomes. The program was planning to award up to 80 percent of the incentive fee before the Critical Design Review (CDR), despite the fact that much of the results of the contractor's work would not be known until after this review. If the Army and Marine Corps are to undertake ambitious developmental efforts in an age of austerity, they must ensure that work is contracted in a manner that facilitates and incentivizes the efficient use of scarce resources. See Government Accountability Office, *Defense Acquisitions: Role of Lead Systems Integrator on Future Combat Systems Program Poses Oversight Challenges*, (Washington, DC: Government Accountability Office, 2007). The problems with Army acquisition and potential corrective actions are explored in depth in Office of the Secretary of the Army, *Army Strong: Equipped, Trained and Ready, Final Report of the 2010 Army Acquisition Review*, (Washington, DC: Department of the Army, 2010).

"lessons learned" during earlier production.[158] Acquiring cheaper OTS systems when they will suffice would free up resources that could be used to address other, higher priorities.

> UNDERTAKING AMBITIOUS DEVELOPMENTAL EFFORTS ONLY IN LIMITED CIRCUMSTANCES AND FOR SPECIFIC COMPELLING CAUSES. There may well be a compelling case made by the Services that certain needs can be met only by fielding a next-generation vehicle. In such cases, the burden of proof should be on the Services to demonstrate *conclusively* that neither of the more affordable approaches above will prove sufficient, and that developing a new vehicle (and the costs and risk entailed) is justified by that new vehicle's greatly enhanced ability to address a major risk or seize an opportunity that, with a high degree of assurance, could result in a major leap in operational effectiveness.

This approach is dictated by necessity, not choice, and it has drawbacks. A more ambitious modernization program featuring greater emphasis on developing all-new vehicles might result in Army and Marine Corps vehicle portfolios that are better suited to the demands of the future security environment, but only if that modernization program is fully resourced. If, instead, such a modernization program were founded on unrealistic assumptions regarding available resources and the likelihood of cost overruns, the fate of such programs would likely be the same as many others in recent years, such as the FCS and EFV programs. In an age of austerity, the less ambitious approach suggested represents a more realistic—and hence more responsible—modernization strategy. But this approach must be balanced by the complementary actions described below.

Defense planners and vehicle designers need to mitigate the consequences of uncertainty by maximizing the adaptability of new and recapitalized vehicles.

MAXIMIZING ADAPTABILITY

Given the inherent uncertainty in the future security environment and the likelihood that surprise will not be entirely avoidable, defense planners and vehicle designers need to mitigate the consequences of uncertainty by maximizing the adaptability of new and recapitalized vehicles. Doing so will enable the ground forces to hedge against the possibility—indeed, the *likelihood*—that these vehicles will need to be modified or upgraded to perform new or altered missions, and meet new operational requirements as they emerge.

Former Secretary of the Navy Richard Danzig offers one vision of how adaptability can be maximized. "At the simplest level," he states in his work *Driving in the Dark: Ten Propositions About Prediction and National Security*, "the ideal

[158] That is to say that the United States would accrue the benefits of problems solved and efficiencies discovered during prior production for other customers.

is the Lego set, with its universal snap-in interface."[159] Of course, as Danzig acknowledges, "Lego pieces need to be matched in only three spatial dimensions … [while] components of complex systems require compatibility in many domains." Still, he favors utilizing open architecture platforms designed with basic capabilities to which mission-specific capabilities could be added as needed. One such system is the B-52 bomber, which he describes as an "airplane with high inherent resilience; essentially a flying box, [that can be] used as a platform for weapons, communications and missions that were not, indeed could not have been, envisioned by its designers." As Danzig further notes,

> DOD should maximize the platform approach suggested by the B-52 example. Using a software analogy, the basic weapon platform is like the operating system, and the addition and delivery of additional focused capabilities is like the installation and use of applications. Designing systems that provide only generic sets of capabilities (platforms) yet can readily be customized and adapted for particular uses (applications), will often yield more long-term value and efficiency than developing a system with a rich but narrowly focused set of capabilities that is more "efficient" according to bureaucratic, nonoperational and predictively biased standards.[160]

The software/application model is appealing. To its credit, it has arguably already been applied with great success to ground vehicles. The M113, for example, would seem to fit Danzig's concept of a useful "box."[161] Designed in the late 1950s as an armored personnel carrier (APC), it has been modified to serve in many other roles, including light tank, mortar carrier, ambulance, mobile command post, self-propelled anti-aircraft gun, and ballistic missile launch platform among others, and has spawned an M113 "family of vehicles" with over 40 members, many of them still in service over 50 years later.[162] Other platforms, such as the *Humvee* and *Stryker*, have proven similarly adaptable to a variety of missions and functions.

For all their adaptability, however, the basic platforms on which these families of vehicles are based have only so much capacity for modification. This is bounded in large part by the amount of surplus space, weight, and power (SWaP) that can be utilized for modifications without requiring extensive vehicle redesign. The amount of SWaP available on a ground vehicle platform is determined by the chassis, which comprises complementary parts that cannot be readily interchanged like Lego pieces. To employ Danzig's software analogy, it is no more feasible to place 40 tons of armor and weapons on a chassis designed to support and move

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[159] See Richard J. Danzig, *Driving in the Dark: Ten Propositions About Prediction and National Security* (Washington, DC: Center for a New American Security, 2011), p. 23.

[160] Ibid., p. 24.

[161] Indeed, the M113 has been called a "box on tracks," not necessarily an affectionate nickname.

[162] "U.S. Army Factfile: M113 Family of Vehicles," available at, http://www.army.mil/factfiles/equipment/tracked/m113.html, accessed on December 7, 2011.

20 tons of weight than it is to run a 64-bit application on a 32-bit processor. What, then, can plausibly be done to maximize the adaptability of ground vehicles?

One possible approach may be to emphasize "growth room" in a ground vehicle's design in the form of surplus space, weight, and power capacity beyond that which is required for envisioned mission(s). This emphasis could manifest itself, for example, in the deliberate inclusion of unoccupied spaces under the armor of a vehicle, the use of heavier-duty engines and suspensions than what appears immediately required, or alternators and batteries that provide and store more electrical power than needed to run the electronic systems initially in use. Of course, designing to include "surplus" may find a vehicle sub-optimized for its projected mission set.[163] Designing in surplus capacity may also run contrary to instincts of many engineers, who might adhere to Antoine de Saint-Exupery's maxim that "perfection is reached not when there is nothing left to add, but when there is nothing left to take away." It may also be anathema to acquisition decision makers who, given prospective resource constraints, will likely be under pressure to choose the cheapest design that meets minimum requirements, discounting or even ignoring the value of SWaP.

Yet while "surplus" capacity may sound frivolous, it could prove invaluable in an age of relatively high geopolitical and military-technical uncertainty in which frequent and/or rapid modifications may be needed to meet new requirements and keep pace with evolving threats. A senior engineer at the Army's Tank-automotive and Armaments Command (TACOM) summed it up best:

> We want growth to be built in. We can't shave our platforms down so they just meet the current requirements and don't have a growth path … We have to allow for the application of additional capability.[164]

While "surplus" capacity may sound frivolous, it could prove invaluable in an age of uncertainty.

EXPLORING KEY TECHNOLOGIES

While leveraging past investments to the maximum extent possible in order to conserve resources, the Army and Marine Corps must not neglect potential opportunities to identify and exploit the "next big thing" in ground vehicle design. Science and technology (S&T) funding is the "seed corn" of future capabilities, and should be protected. In particular, the forecast of future challenges and their

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[163] To offer a classic and highly successful illustration of this approach, the U.S. Navy's *Spruance*-class destroyers were heavily criticized as expensive and seriously under-armed when they were first delivered in the 1970s. But their large volume, displacement, and electrical generation spare capacities enabled the easy subsequent installation of major new weapons systems such as Vertical Launch System modules, Tomahawk cruise missiles, and the SH-60 Seahawk antisubmarine warfare (ASW) helicopters, making those ships among the most heavily armed destroyers of their day.

[164] Chris Williams, "Top Scientists Seek Lighter, Tougher Materials to Increase Survivability," *GVSET News*, 8, No. 2, March 2011.

implications for ground vehicles described in earlier chapters suggest several candidate areas for prioritized S&T investment, including

> Novel survivability enhancements;

> Fuel efficiency improvements; and

> Robotic systems.

Novel Survivability Enhancements

The trends outlined above suggest the future battlefield will be more lethal for U.S. ground forces, making force protection more difficult. Lightweight armor that provides a major and enduring boost to vehicle and crew protection while at the same time significantly reducing vehicle weight (and thus fuel consumption) represents a "holy grail" of sorts for ground force vehicle designers. Toward this end investments in areas like nanotechnology and materials science seem warranted. To be sure, a breakthrough in this area has long been sought with little result, but the prospective benefits appear sufficiently attractive as to justify significant Army and Marine Corps S&T "wildcatting" efforts.

Technologies associated with enhanced situational awareness also seem worthy of continued investment. Although vehicles that incorporate greater situational awareness are not a true substitute for armor, it can enhance their survivability and that of their crews. This is especially true in urban combat, where the difficulty that armored fighting vehicle crews experience in observing and understanding what is going on around them may severely inhibit their effectiveness and make them heavily reliant on accompanying infantry. Situational awareness becomes even more important when infantry support is unavailable or lost due to enemy action.[165] Systems that improve vehicle crews' ability to see what is going on in areas not visible through sights or periscopes (e.g., via panoramic cameras), to locate threats (e.g., through use of acoustic gunfire locators), and to identify and communicate with friendly forces (e.g., blue force trackers, vehicle-dismounted infantry communications networks) could significantly enhance the vehicle effectiveness and survivability in urban settings.

A third subset of survivability enhancements comprises vehicle-mounted countermeasures for battlefield G-RAMM, which are likely to pose the greatest tactical-level threat to ground vehicles. Investing in vehicle-mounted countermeasures against both direct-fire (e.g. ATGM) and indirect-fire (e.g. mortar) threats might enable the ground forces to mitigate this threat. These countermeasures will likely be expensive, but their development and fielding will likely be more affordable

[165] For a harrowing illustration of the importance of situational awareness in urban combat, see an account of the Russian 131st "Maikop" Independent Motorized Infantry Brigade in Grozny, Chechnya, in Gott, *Breaking the Mold*, pp. 71-90.

if it occurs at a smooth pace ahead of hostilities instead of in a frantic rush to meet urgent operational needs following the first encounter between U.S. ground forces and a G-RAMM enabled enemy. Such countermeasures appear to be maturing rapidly, especially overseas,[166] which suggests that their underlying technologies are relatively mature and that systems like this could be fielded in the near-term future. As mobility and coordination with infantry are likely to play a role in defeating the threat posed by these systems, ideal countermeasures should have a minimal impact on vehicle mobility and pose little risk of collateral damage to accompanying infantry.[167]

Improved Fuel Efficiency

If, as seems likely, sustaining U.S. ground forces using current capabilities and operations becomes progressively more difficult, one way to address the challenge will be to reduce the logistical demands of forces in theater. Reducing vehicle fuel consumption, which accounts for one-fifth of the total logistical burden of deployed forces, would be a major step in this direction.[168] Toward this end, investments in promising technologies to substantially reduce the volume of fuel required by troops in theater appear are warranted. According to the Defense Science Board, reductions in ground vehicle fuel demand could be realized via three "pathways":

> System level changes, such as new vehicle configurations improving overall efficiency, new propulsion architecture (e.g., hybrid-electric propulsion systems[169]), and new fuels (over the long-term, perhaps derived from advances in energetics).

> Major subsystem increments, such as step improvements in engines and motors (i.e. more efficient diesel engines); and the pervasive introduction of lighter structural materials.

> Small component evolutions (e.g., more efficient generators, material substitution).[170]

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[166] Examples of the current state of the art include the active Israeli Trophy system (also known as ASPRO-A) that detects incoming projectiles with radar and destroys them with focused, shotgun-like blasts of buckshot, and the passive Russian Shtora ("curtain") system, which uses a laser warning system and a combination of smoke screen projectors and infrared lights to defeat the guidance systems of incoming ATGMs.

[167] Active protection systems deal with incoming projectiles by firing their own interceptor projectiles outwards. These interceptors can potentially cause collateral damage to friendly troops (and other objects in the surrounding area).

[168] Although it could have financial, environmental, and strategic benefits, use of alternative fuels (e.g. hydrogen, ethanol and other biofuels) would not address the operational issue unless they became far easier to transport in quantity.

[169] Although the focus here is on reducing fuel consumption, hybrid-electric propulsion systems offer other benefits as well, such as greater exportable power.

[170] *More Fight—Less Fuel*, p. 37.

Significant advances in all three categories appear promising in the near- to mid-term, as demonstrated by the performance of several prototypes that collectively incorporated changes in all three areas.[171] Unfortunately, technological maturity may not be the primary obstacle to their fielding.

As with surplus SWaP capacity, fuel efficiency must be properly emphasized in the ground vehicle requirements process and in design competitions. Historically, this has not been the case. Estimates of fuel efficiency value have been based on the wholesale cost of fuel from the Defense Energy Support Center, not the "fully burdened" cost of fuel (FBCF), which accounts for delivery costs—to include the forces that protect fuel as its being delivered—and is therefore significantly higher. The M1 Abrams, for example, was designed in the late 1970s with the explicit assumption that its fuel would cost $1 per gallon, with no delivery costs.[172] As a recent RAND study noted,

> [W]hen we design our future capabilities in the Pentagon or at the major Service materiel commands and elsewhere, logistics demand[s] of our capability choices are not addressed until after we have decided on what that performance our platforms or combat units should have [sic]. Stated more simply, our force planning processes almost always plug fuel logistics in at the back end, after the capability we want is designed. The result is that we plan capabilities and systems ignorant to the combat support "tail" we are creating … at no point [do] the force development processes consider whether it's worth it to reduce the logistics demand to gain unit or theater deployability, vulnerability, or sustainability benefits. Finally, we have little to no analysis on which to determine what it's worth to the larger force to invest in fuel efficiency technologies.[173]

As the Defense Science Board noted in 2008, "Technologies that could reduce the fuel demand of a deployed system but which do not appear cost effective if the fuel cost is assumed to be $2.50 per gallon might be extremely compelling

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[171] Numerous prototypes developed by the Services, DARPA, and industry have demonstrated the relevant technologies' potential. For example, the Army has developed an up-armored Humvee design known as Fuel Efficiency Demonstrator Alpha (FED Alpha), which incorporates an advanced diesel engine (a major subsystem increment) and small component evolutions incorporating lighter-weight materials. One prototype has been undergoing trials at Aberdeen Proving Grounds since July 2011 and has demonstrated a fuel consumption rate 70 percent lower than a standard up-armored Humvee. System level changes such as the use of hybrid-electric propulsion systems also appear feasible, based on the performance of several prototypes and the existence of a hybrid diesel-electric variant of the HEMTT also undergoing evaluations at Aberdeen. Gary Sheftick, "Demo Humvee Burns 70 Percent Less Fuel," *Army.mil*, October 18, 2011; and Paul McLeary and Kimberly Johnson, "Hybrid Vehicles Are In U.S. Military's Future," *AviationWeek*, May 4, 2011.

[172] Amory Lovins et al, *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security* (Snowmass, CO: Rocky Mountain Institute, 2005), p. 87.

[173] Chris DiPetto, quoted in Terrence K. Kelly, John E. Peters, Eric Landree, Louis R. Moore, Randall Steeb, and Aaron L. Martin, *The U.S. Combat and Tactical Wheeled Vehicle Fleets: Issues and Suggestions for Congress* (Santa Monica: RAND Corporation, 2011), pp. 64-65.

if the actual cost of moving and protecting the fuel were used instead."[174] Some estimates have pegged the fully burdened cost of a gallon of fuel in Afghanistan as high as $400.[175] This issue has recently received increased attention as a result of a 2008 Defense Science Board study.[176] Since then, the Department of Defense has created an "Energy Efficiency Key Performance Parameter" (KPP) that is to be considered in its analyses of new system requirements and alternatives, and has mandated that the acquisition process take into account the fully burdened cost of fuel.[177] It remains to be seen, however, how these costs will be calculated and what effect they will have on acquisition decisions.[178]

Robotic Systems

Given the likely enduring U.S. priority on maintaining high levels of force protection and the increasingly lethal future operating environment forecast in earlier chapters, robotic systems represent a promising area of technology investment. By removing human operators from situations in which they are especially vulnerable, robotic systems could reduce the need for force protection measures, and relieve vehicles of the many design penalties that the demand for force protection (generally met with heavy armor) imposes. Such vehicles could be particularly valuable in the performance of roles characterized by the "three Ds": dirty, dull, and dangerous. Ground vehicles (and their crewmen) are often involved in such work, and therefore make appealing candidates for replacement by robotic systems.

The robotic systems of interest include both true unmanned ground vehicles (UGVs) that are autonomous or remotely operated with no human crewmen aboard, and robotic enhancements to manned ground vehicles. Although robotic enhancements to manned vehicles and small, remotely operated UGVs have been

Given the likely enduring U.S. priority on maintaining high levels of force protection and the increasingly lethal future operating environment forecast in earlier chapters, robotic systems represent a promising area of technology investment.

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[174] *More Fight—Less Fuel*, p. 28.

[175] Roxana Tiron, "$400 per Gallon Gas to Drive Debate Over Cost of War in Afghanistan," *The Hill*, October 15, 2009.

[176] *More Fight—Less Fuel*, February 2008. The report concluded that "Improving the efficiency of a deployed system would reduce the amount of fuel needed for battle, and hence the number of the fuel logistics assets the DoD would need to buy, maintain, train on, buy fuel for, and protect. The costs of those assets should be included in calculating the true cost of fuel to DoD, and should be compared with the cost to make deployed systems more efficient."

[177] Statement of Deputy Under Secretary of Defense for Installations and the Environment, Dr. Dorothy Robyn, Before the Senate Homeland Security and Governmental Affairs Committee, Subcommittee on Federal Financial Management, Government Information, Federal Services, and International Security, January 27, 2010.

[178] For a good example of analysis that gives these costs the consideration they deserve, see *Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys – Final Technical Report* (Arlington, VA: Army Environmental Policy Institute, 2009).

fielded and employed, often to great effect, in the Iraq and Afghanistan wars,[179] the potential of unmanned systems appears to be largely untapped. Admittedly, land warfare is a more complex environment in which to maneuver and operate systems than the sea or air environments, posing challenges to UGVs that unmanned air and sea vehicles need not overcome, such as negotiating rough terrain and maneuvering among heavy pedestrian and vehicle traffic. These challenges have proved very demanding for Army and Marine Corps UGV development efforts. Still, gradual progress is being made and offers hope that these challenges might be overcome. The steadily improving performance of entrants in the DARPA Grand Challenge[180] (an off-road endurance race for autonomous ground vehicles) and Google's Driverless Car,[181] for example, give the impression that the fielding of fully autonomous ground vehicles in the mid-term future might be feasible.

These encouraging developments suggest that the ground forces could begin exploring the potential of "unmanning" vehicles that carry out relatively simple duties—logistics trucks, for example. These vehicles often spend a great deal of their lives following predictable, plottable courses over hardball roads in convoy serials, maintaining a relatively fixed position relative to the vehicles in front of them. This would seem to be a relatively easy task for a remote operator or even an autonomous or semi-autonomous navigation system to execute. As the Defense Science Board notes, "autonomous following technology demonstrations, in which a single, manned vehicle leads a convoy of unmanned vehicles, could significantly reduce protection requirements, increase vehicle payload, and minimize the need for onboard communication and situational awareness equipment for the unmanned vehicles in the convoy."[182] It could also save lives.

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[179] For example, the integration of the Common Remotely Operated Weapons Station (CROWS) into combat and TWVs enabled vehicle crewmen to operate roof-mounted weapons from inside the protection of their vehicles, significantly reducing their vulnerability to snipers, IED blasts, and being crushed in rollovers. UGVs have also been used to great effect in explosive ordnance disposal and reconnaissance. Although these robots bear little resemblance to what most people imagine as a vehicle, the fundamental components—propulsion, payload, and the absence of human occupant—are there. They are in fact unmanned ground vehicles, although prohibited by limitations on range, endurance, and capability from carrying out the missions currently performed by manned vehicles. Although the development and fielding of these systems has not been cheap, their costs must be weighed against the potential costs (fiscal and otherwise, as described in Chapter 1) of the human losses that their use has avoided.

[180] In 2004, the "winner" of the Grand Challenge completed 7.3 miles of the 150-mile course. In 2005, five vehicles completed it. In 2007, six vehicles completed a 60-mile course through urban terrain, obeying traffic regulations and negotiating traffic. Wikipedia contributors, "DARPA Grand Challenge," *Wikipedia, The Free Encyclopedia*, available at http://en.wikipedia.org/wiki/DARPA_Grand_Challenge, accessed on December 6, 2011.

[181] Google's Driverless Cars have driven over 140,000 miles with only occasional human intervention and, as of June 2011, may be legally operated on public roads in Nevada. "What We're Driving At," *The Official Google Blog*, October 9, 2010; and Todd Lassa, "Nevada Passes Google's Autonomous Car Bill," *Motor Trend*, June 29, 2011.

[182] *The U.S. Combat and Tactical Wheeled Vehicle Fleets: Issues and Suggestions for Congress* (Santa Monica, CA: RAND Corporation), 2011, pp. 67-68.

Longer term (allowing for plausible advances in UGV technology), the ground forces might seek to employ unmanned systems in more complex combat roles. The recently proposed concept of "unmanned breacher vehicles" that could be used during amphibious landings to clear the path for manned vehicles is illustrative of the kind of ideas the ground forces could benefit from exploring.[183] Of course, there could be reasons to keep a "man in the loop." Combat vehicles that are remotely controlled (as opposed to autonomous) appear easier to achieve and perhaps cheaper as well, but might not be sufficient in the future should the electromagnetic spectrum grow increasingly contested. Should assured communications be denied on the battlefield of the future, the ground forces might find themselves needing fully autonomous systems, though the Department of Defense in general appears at present to have serious reservations about armed, autonomous systems at present.[184]

Should unmanned vehicles—whether autonomous or remotely operated—grow capable enough to carry out the functions that currently require human crews it could be a potential "game changer" for vehicle design. Reaching this level of sophistication could, as a RAND study noted,

> radically alter the trade space for vehicles. By eliminating the need to protect soldiers and marines in some vehicles, the weight requirement would lessen, with the attendant gains in all other variables that trade off with weight. Similarly, fuel consumption, other logistics requirements, and strategic mobility could be significantly enhanced.[185]

S&T should be pursued independently of the development of particular platforms.

Final Note

Like most S&T investments, there is no guarantee investments in particular areas will be fruitful or result in fielded capabilities. The technologies noted above have promise, but may nonetheless be slow to mature. Thus, as a general consideration, S&T in these and other areas should be pursued independently of developing particular platforms to avoid protracting an already sluggish procurement process, and the increased costs of doing so. Rather, emphasis should be placed on prioritizing SWaP to enable technological breakthroughs to be retrofitted to the existing vehicle fleet to the maximum extent possible.

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[183] Noel Williams, "The Next Wave: Assault Operations for a New Era," *Proceedings*, 137 No. 11, November 2011.

[184] Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: Center for Strategic and Budgetary Assessments, 2006), pp. 280-283.

[185] Kelly et al, *The U.S. Combat and Tactical Wheeled Vehicle Fleets: Issues and Suggestions for Congress*, RAND Corporation, 2011, pp. 68.

PRESERVING THE DEFENSE INDUSTRIAL BASE

In an "age of austerity," funding for new systems is likely to be much less than in the recent past. Consequently, both the Army and Marine Corps need to take into account the second-order effects of decisions regarding the ground vehicle fleet on the defense industrial base (DIB). The DIB has long been a major U.S. strategic asset. An extended period of austerity will necessarily bring about contraction of the DIB, just as it has in previous periods of retrenchment following the end of World War II and the collapse of the Soviet Union. During such periods, some design and manufacturing capability could be lost that could be difficult and expensive, if not impossible, to regenerate later.

To ensure that access to critical ground vehicle design and manufacturing capabilities are maintained, the Army and Marine Corps must identify the most vital capabilities and make a deliberate effort to sustain them in austere times.[186] Although this may require some upfront investment, failure to "pay the freight" here could result in far greater costs to regenerate capacity and skill, and restart production at a later date.[187] It could also preclude the possibility that critical design and production capabilities could be lost if they are not employed for an extended period of time.[188]

If ground vehicles are to be produced or adapted in the future to address changing missions and the evolving demands of the future security environment, the United States will need to have ready the design and manufacturing capability and capacity to do so.

While the health of the defense industrial base might seem a secondary issue or "matter of politics," it is deeply intertwined with the proposition that adaptability may ultimately prove the most salient factor in dealing with the inherent uncertainties regarding future warfare. If ground vehicles are to be produced or adapted in the future to address changing missions and the evolving demands of the future security environment, the United States will need to have ready the design and manufacturing capability and capacity to do so.

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[186] For a more thorough treatment of this idea, see Barry D. Watts and Todd Harrison, *Sustaining Critical Sectors of the U.S. Defense Industrial Base* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011).

[187] For example, one potential case may be the government-owned, contractor-operated (GOCO) Lima Army Tank Plant. The Army currently plans to mothball the M1 Abrams assembly line there during a three-year hiatus in tank production. The contractor operator of the facility, however, asserts that shutting down and restarting production would cost substantially more than keeping the plant running at a low production rate. Whether this is actually the case is uncertain, but it would seem prudent that a greater degree of certainty be reached before irreversible decisions are made. Daniel Goure, "Shutting Down Army Tank Plant May Be A Bad Idea," *Lexington Institute, Early Warning blog*, April 21, 2011.

[188] Although the design and production of ground vehicles is often viewed as relatively unsophisticated when compared to air and naval systems, it still requires specialized knowledge and equipment that may not be readily found in civilian industry. Within the defense industrial base, these assets are concentrated in a handful of production facilities owned by a handful few companies. A sustained decrease in demand could see some of these facilities and/or their owners cease to exist.

CHAPTER 4 > **CONCLUSION**

The main challenges to Army and Marine Corps vehicle modernization efforts are not, in essence, new to defense planners. As noted in this paper's opening quote, uncertainty is "necessarily the lot of the planner, since he deals with the future." Austerity, too, is a familiar experience in the history of U.S. defense policy. That said, the combination of relatively high levels of uncertainty stemming from a dynamic strategic environment combined with the rapid decline of the United States' fiscal posture—a decline that will likely take a decade or more to reverse—suggests that the Services must substantially adapt their traditional approach to vehicle modernization.

In the near-term, the Army and Marine Corps' principal approach with respect to vehicles should be to "use it up, wear it out, make it do, or do without" whenever possible. Over the past decade, both Services have both pursued ambitious combat vehicle development programs and extended the service lives of existing vehicles or settled for readily-available "off-the-shelf" solutions only when—often following the failure of those ambitious programs—there was no alternative. This approach is neither a feasible nor desirable option in these times.

In the near-term, the Army and Marine Corps' principal approach with respect to vehicles should be to "use it up, wear it out, make it do, or do without" whenever possible.

Going forward, the ground Services should reverse their priorities, pursuing recapitalization and off-the-shelf solutions whenever possible and undertaking ambitious developmental efforts only when it is absolutely necessary to provide a capability that cannot be acquired by any other means, or to exploit an extraordinary opportunity (for which the "burden of proof" should be far higher than it has in the recent past).

If and when developing a next-generation vehicle is warranted, the two Services should seek to maximize their adaptability by pursuing an open-architecture approach and deliberately designing in surplus space, weight, and power (SWaP) in order to facilitate future modification. Where possible, these vehicles should not only have "room to grow" to meet future needs, but also the ability to "shrink" (i.e.

shed capability) in order to better suit the needs of unsophisticated partners for whom affordability and ease of maintainability are likely to be high priorities.

While conserving resources and leveraging past investments, the ground Services should not neglect their future. Science and Technology (S&T) funding is the "seed corn" of future capabilities, and its protection should be a priority. The assessment of future challenges presented in this study suggests several candidate areas for high-priority S&T (and perhaps R&D) investment, including *cost-effective* novel protection measures (e.g. active protection systems) especially those that could increase vehicle survivability without increasing vehicle weight; fuel efficiency improvements (e.g. hybrid-electric propulsion) that decrease logistics requirements; and robotic systems (e.g. remote operation) that could remove precious human operators from dirty, dull, and—above all—dangerous roles, while freeing up "trade space" currently occupied by force protection measures.

Army and Marine Corps should identify the sectors of the defense industrial base that are most critical to the design and production of ground vehicles—and that would be difficult to regenerate along acceptable time lines and cost—and invest sufficient resources to sustain them.

Although these technologies may prove valuable in the long-term, most are not sufficiently mature to incorporate into existing vehicles or those under consideration for development and production. This strengthens the case for deferring new vehicle design when possible to avoid incurring large development costs to produce new systems that provide only marginal improvements in effectiveness over the vehicles they are replacing. It further suggests that S&T investments should be pursued independently, rather than being tied to the procurement of new platforms, lest slow maturation of these technologies cause expensive and costly production delays.

To preserve their potential for future growth, the Army and Marine Corps will also have to minimize the adverse impact that scaling back modernization efforts will surely have on the industrial base to ensure it will be able to meet future as well as current needs. Accordingly, the Army and Marine Corps should identify the sectors of the defense industrial base that are most critical to the design and production of ground vehicles—and that would be difficult to regenerate along acceptable time lines and cost—and invest sufficient resources to sustain them.

The approach outlined above offers the Army and Marine Corps a way of approaching the challenge of managing their fleet of ground vehicles in a way that represents a significant improvement over the approach followed in the post-Cold War era. It addresses the need to adapt to an era of austerity while mitigating the

risks and consequences of surprise that are likely to emerge over the next several decades—to include those driven by the seven key trends in land warfare identified above.

That said, the approach recommended in this report does not provide a panacea for the growing challenges and costs associated with projecting and sustaining decisive land power. The battlefields of the future will almost certainly be more lethal than those of the present; the result of the proliferation of guided and nuclear weapons, growth of urban terrain, and the ability of adversaries to field anti-armor weapons faster and at a lower cost than the U.S. can improve vehicle protection. These challenges will be exacerbated by the U.S. priority on achieving unprecedented levels of force protection.

In summary, meeting the challenges posed by emerging changes in the character of land warfare will require more than a better approach to thinking about ground vehicle requirements and design with growing resource constraints. If the Army and Marine Corps are to maintain the ability to project and sustain decisive land power, it will involve a broader consideration of the problem. Such an effort should involve an examination of new operational concepts that explore how the ground forces might deploy, fight, and sustain themselves more effectively in a far less permissive environment. These concepts should identify what role the other Services (i.e., the Air Force and Navy) can play in supporting the ground force. Finally, to the extent the Defense Department is serious about executing its strategy of placing far greater emphasis on the role of ally, partner, and indigenous forces (i.e., "building partner capacity"), such forces should play a major role in the development of any new operational concept.

While addressing this issue is far beyond the scope of this report, prudence suggests the Army and Marine Corps should give strong consideration to addressing it thoroughly before finalizing a strategy for their future ground vehicle fleets.

GLOSSARY:

A note on terminology: this report employs the broad term "ground vehicles" to refer to all vehicles used on land by the U.S. Army and Marine Corps, to include both those designed for combat roles and logistical roles. Other terms, including several used in this report to describe subsets of ground vehicles with particular roles or characteristics, are described below.

Armored fighting vehicle (AFV)—a vehicle, wheeled or tracked, protected by strong armor and armed with weapons. Examples: M1 Abrams, M2 Bradley, M109 Paladin, M113, Armored Multi-Purpose Vehicle (planned), Stryker, Ground Combat Vehicle (planned), Expeditionary Fighting Vehicle (cancelled), AAV-7, LAV-25, Marine Personnel Carrier (planned).

Armored personnel carrier (APC)—a vehicle, wheeled or tracked, intended to transport infantry to the battlefield, but not intended to play a direct role in combat (unlike infantry fighting vehicles). Example: M113, Armored Multi-Purpose Vehicle (planned).

Battlefield G-RAMM—a subset of G-RAMM comprising precision-guided weapons with ranges of less than 20 miles. Examples: anti-tank guided missiles (ATGMs), guided mortar rounds, guided artillery rounds, guided artillery rockets, man-portable air defense systems (MANPADS).

Combat vehicle—(Army term) a vehicle (wheeled or tracked) designed to participate directly in combat. Distinguished from "tactical wheeled vehicles" (such as Humvee, MRAP) even though such vehicles engage in combat. Examples: M1 Abrams, M2 Bradley, M109 Paladin, M113, Stryker, Ground Combat Vehicle (planned), M113, Armored Multi-Purpose Vehicle (planned), Expeditionary Fighting Vehicle (cancelled), AAV-7, LAV-25, Marine Personnel Carrier (planned).

Infantry fighting vehicle (IFV)—a vehicle, wheeled or tracked, intended to transport infantry into battle and to support them in combat. A subset of armored personnel carriers, generally distinguished by heavier firepower and a direct fire support role in combat. Examples: M2 Bradley, Ground Combat Vehicle (planned), Stryker, Expeditionary Fighting Vehicle (cancelled), Amphibious Combat Vehicle (planned), Marine Personnel Carrier (planned).

Tactical wheeled vehicle (TWV)—(Army term) a wheeled vehicle designed primarily for transport and other roles that have historically been behind the front lines. Distinguished from "combat vehicles," even though many TWVs (e.g. Humvees, MRAPs) are armed, armored, and regularly engaged in combat. Examples: Humvee, JLTV (planned), MRAPs, medium trucks (FMTV, MTVR), heavy trucks (HEMMT, LVS, PLS, HET).

Theater G-RAMM—a subset of G-RAMM comprising precision-guided weapons with ranges in the multiple tens or hundreds of miles. Examples: cruise missiles, ballistic missiles, long-range surface-to-air missiles.

ABBREVIATIONS:

A2/AD	Anti-Access/Area-Denial
AFV	Armored Fighting Vehicle
AMPV	Armored Multi-Purpose Vehicle
APC	Armored Personnel Carrier
APOD	Aerial Port of Debarkation
APS	Active Protection System
ATGM	Anti-Tank Guided Missile
C2	Command and Control
CONUS	Continental United States
CUCV	Commercial Utility Cargo Vehicle
DIB	Defense Industrial Base
DoD	Department of Defense
EFP	Explosively Formed Penetrator
EFV	Expeditionary Fighting Vehicle
ERA	Explosive Reactive Armor
FCS	Future Combat Systems
FY	Fiscal Year
GCV	Ground Combat Vehicle
G-RAMM	Guided Rockets, Artillery, Mortars, and Missiles
IDF	Israeli Defense Forces

IED	Improvised Explosive Device
IFV	Infantry Fighting Vehicle
ISR	Intelligence, Surveillance, and Reconnaissance
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JLTV	Joint Light Tactical Vehicle
MANPADS	Man-Portable Air Defense Systems
M-ATV	Mine-resistant, All-Terrain Vehicle
MGV	Manned Ground Vehicles (FCS)
MPC	Marine Personnel Carrier
MRAP	Mine-Resistant, Ambush Protected [vehicle]
OTS	Off-The-Shelf
PGW	Precision Guided Weapon
R&D	Research and Development
RPG	Rocket Propelled Grenade
S&T	Science and Technology
SPOD	Sea Port of Debarkation
SWaP	Size, Weight, and Power
UGV	Unmanned Ground Vehicle

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