CSBA

Center for Strategic and Budgetary Assessments

HUMAN-MACHINE TEAMING FOR FUTURE GROUND FORCES

MICK RYAN

HUMAN-MACHINE TEAMING FOR FUTURE GROUND FORCES

MICK RYAN

CSBA

Center for Strategic and Budgetary Assessments

2018

ABOUT THE CENTER FOR STRATEGIC AND BUDGETARY ASSESSMENTS (CSBA)

The Center for Strategic and Budgetary Assessments is an independent, nonpartisan policy research institute established to promote innovative thinking and debate about national security strategy and investment options. CSBA's analysis focuses on key questions related to existing and emerging threats to U.S. national security, and its goal is to enable policymakers to make informed decisions on matters of strategy, security policy, and resource allocation.

ABOUT THE AUTHOR

Mick Ryan is a Major General in the Australian Army. A graduate of Johns Hopkins University, the USMC Staff College, and the USMC School of Advanced Warfare, he is a passionate advocate of professional military education, global PME discourse, and lifelong learning. In January 2018 he assumed command of the Australian Defense College in Canberra.

ACKNOWLEDGEMENTS

Cover Graphic:

U.S. Army Pacific Soldiers, 25th Infantry Division, move in formation while controlling unmanned vehicles as part of the Pacific Manned-Unmanned Initiative at Marine Corps Training Area Bellows on July 22, 2016. The photo is by Staff Sgt. Christopher Hubenthal.

Contents

Figures

The Near Future

The artificial intelligence (AI) algorithmic command decision support system had been analyzing their joint battle group plan of operations for 45 minutes. Merlin, as it was affectionately known, announced it had completed its analysis cycle of 10,000 wargame simulations with a crisp, staccato "ping!" In the rear of the their blacked-out armored command vehicle, the battle group operations officer, Major Kinsley, looked over the summary dashboard Merlin published before handing the tablet to his commander. He shifted in his seat to talk the Colonel through the highlights.

Colonel Bryant took the tablet. "How's it look, Steve?" he asked.

It wasn't all good news. "Merlin thinks the ratio of friendly to enemy forces looks about right. That's the good news. But it looks like we'll need to execute the urban breach and initial phases earlier. Also, we'll need to use more directed energy emitters and about twice the precision guided munitions forward in the initial push."

Bryant wasn't looking forward to leading with the relatively delicate self-propelled directed energy emitters. He was reassured though by the recommendation for more of the precision guided munitions—they'd offset the risk of the temperamental directed energy emitters.

"Make sure it's synchronized with the cyber, air swarm, and subterranean operations teams. While you're at it, grab the communications officer and find out where we are with the cryptography update for all of our unmanned ground vehicles."

Kinsley looked at his eye-activated Heads Up Display and visually toggled through the menus on the orders board. It moved as fast as Kinsley could see and click on his hand set.

"Mmmm; Not done yet, sir. But looks like less than an hour."

The security update for the Unmanned Ground Vehicle fleet was a critical part of the plan for tomorrow morning's operation to move into the fortified zone of the city. The fleet of unmanned ground vehicles would provide a massed surveillance, reconnaissance, retransmission, and engagement capability for their operations. Although generally reliable, they had been susceptible to enemy interference in the past. Daily security updates had become a standard procedure. Bryant handed Kinsley back the tablet.

"OK, confirm the amendments Merlin recommended and then publish the final order through to the battle group. Virtual rehearsal starts in 45 minutes. Thanks, Steve." Bryant twisted to exit the rear of the vehicle. And then paused.

"Oh, and tell the team in the forward repair group that I want all of our exoskeleton battle suits available this time. If I must, I'll go to the boss for extra log-drones to fly them out here."

Emerging from the armored command vehicle with low visibility camouflage, Bryant approached the two kneeling figures positioned just outside the hatch.

"So, we go at zero three hundred. What do you have for me?" He listened as the Human Intelligence and Social Media team leaders updated him on likely population and community leader responses to his move into the city. He looked at their heat maps of population sentiment and wondered how they'd look this time tomorrow. . .

Introduction

By the middle of the 21st century, ground forces will employ tens of thousands of robots, and the decisions of human commanders will be shaped by artificial intelligence. Although the future is impossible to predict, trends in technology and warfare make this a near certainty. Military organizations must plan now for this new era of warfare. Governments must be prepared for the political, strategic, and ethical dimensions of this shift in the character of war.

In his book *On War*, Carl von Clausewitz highlighted how failing to understand the character of war leads to disaster. Discussing the Prussian defeat in 1806, he chastised Prussian generals for using the old tactics of Frederick the Great against a Napoleonic army waging a new type of warfare.[1] They had not appreciated the changes in how war was being fought or in the character of war. The future development and deployment of human-machine teams and autonomous weapons systems represents such a shift in the character of war.

In 2017, the United States Army published its strategy for the development and deployment of robotic and autonomous systems. This strategy outlines activities for the U.S. Army that will provide a wider range of robotic capabilities to secure U.S. national security objectives over the next two decades.[2] However, the U.S. Army is not the only institution that can benefit from the enhanced teaming of humans and machines in the future; the ground forces of U.S. allies and partners can enhance their operational and institutional effectiveness through this approach as well.

---

[1]   Carl von Clausewitz, *On War*, Michael Howard and Peter Paret, eds. and trans. (Princeton, NJ: Princeton University Press, 1984), pp. 154–155.

[2]   U.S. Army, *Robotic and Autonomous Systems Strategy* (Fort Eustis, VA: U.S. Army Training and Doctrine Command [TRADOC], March 2017), p. i.

This study examines the key drivers, opportunities, and challenges for ground forces in developing future human-machine teams. It provides an intellectual foundation for the detailed analysis of the personnel, equipment, training, education, doctrine, sustainment, and infrastructure required by a future human-machine force.

Chapter one examines the rationale for ground forces investing in human-machine teaming. It addresses the development of human-machine teaming for combat operations and its potential in a wide range of ground force activities. This includes combat, preparing for combat, modernization, doctrine, education, and training.

Chapter two analyses three areas that offer future ground forces a competitive advantage in war: human-robot teaming, human-AI teaming, and human augmentation.[3] Each will pose challenges to the training, resourcing, and culture of ground forces.

Chapter three reviews the key challenges in developing future human-machine teams. Strategic, institutional, and tactical issues are considered in this section of the paper.

Chapter four proposes a strategy to improve future ground force performance through human-machine integration. A key theme is that human-machine teams have applications beyond the battlefield. These applications extend across the entire enterprise of raising, training, sustaining, and employing ground forces. A strategy that includes all aspects of a ground force's institutional activities—from those on the battlefield to strategic decision-makers—ensures organizations can develop a competitive advantage through human-machine integration.

---

[3]   Recent U.S. military efforts have focused on five lines of endeavor: autonomous deep learning systems; human-machine collaboration; assisted human operations' advanced human-machine combat teaming; and network-enabled cyber-hardened autonomous weapons. See "Remarks by Defense Deputy Secretary Robert Work at the CNAS Inaugural National Security Forum," Center for a New American Strategy, December 14, 2015, available at https://www.cnas.org/publications/transcript/remarks-by-defense-deputy-secretary-robert-work-at-the-cnas-inaugural-national-security-forum.

FIGURE 1: AUTONOMOUS TRUCK CONVOY

A convoy of driverless Army trucks makes its way through the Department of Energy's Savannah River Site in South Carolina, May 29, 2014. Photo Credit: U.S. Army Tank Automotive Research, Development and Engineering Center.

Chapter 1

The Imperative: Human-Machine Teaming on and Beyond the Battlefield

After the relative peace of the 1990s, the United States, Europe, and ally nations around the world found themselves engaged in sustained combat and stabilization operations across the Middle East at the start of a new millennium. These operations did not conform to the scenarios around which the force structures and operating concepts honed over many decades of the Cold War were sized and shaped. It necessitated organizational adaptation and innovation across the fields of equipment, tactics, logistics, training, and education.

Western ground forces now similarly find themselves at a new crossroads. Large-scale operations in Iraq and Afghanistan have mostly concluded and have been replaced by smaller "economy of effort" operations to train indigenous forces. Concurrently, the world in which military organizations have operated over the past two decades is rapidly changing.

Many Western governments and military organizations have attempted to identify prevailing trends that will drive or influence strategy and national policy. Likewise, military organizations around the world are studying the changing character of war to inform force structure and procurement decisions. The uncertainty of the future security environment confounds precise predictions of the future. Prudence demands that governments and military organizations outline a range of probable futures based on prevailing trends to inform their planning.

Assessments of the future security environment from Canada, the United States, the United Kingdom, Australia, and New Zealand[4] contain several common themes; significant changes in demographics and urbanization, geopolitics, economics, the role of the state, the diffusion of power, climate and resources, and emerging and disruptive technology are forecasted. These will not only affect the policy and strategy of nations but will also drive changes in the character of war and future ground force operations.

Strategic Drivers for Change in Ground Forces

Although there are many trends, three key areas of change will most likely affect future ground forces the most: geopolitics, the changing nature of work, and the disruptive impact of robotics and AI.

Geopolitics

With the military growth and modernization of revisionist powers such as China and Russia, the character of military operations for ground forces will likely evolve. Both powers have invested heavily in conventional military capabilities, including qualitative improvements in a range of ground force organizations. For Russia, this investment was driven by the rapid military modernization of its neighbors and the understanding that a strong nuclear force alone would not secure Russia's great power status.[5] For China, the ongoing investment in conventional forces is part of the Chinese Communist Party's stated aim of becoming a great power.[6]

In this environment, preparing for large-scale ground operations is once again an imperative for Western ground force design. This does not negate the need for ground forces to prepare for smaller-scale contingencies. But even these smaller-scale engagements will be influenced by the presence of weapon systems, sensors, and cyber capabilities developed for high intensity

---

4   Ministry of Defence (MOD) UK, *Global Strategic Trends—Out to 2045* (Shrivenham, UK: Development, Concepts and Doctrine Centre, June 30, 2014); MOD UK, *Future Operating Environment 2035* (Shrivenham, UK: Development, Concepts and Doctrine Centre [DCDC], December 14, 2015); David T. Miller, *Defense 2045: Assessing the Future Security Environment and Implications for Defense Policy Makers* (Washington, DC: Center for Strategic and International Studies, November 2015); Directorate of Future Land Warfare, *Future Land Warfare Report* (Canberra: Australian Army Headquarters, 2014); Army General Staff, *Future Land Operating Concept 2035: Integrated Land Missions* (Wellington, NZ: Headquarters New Zealand Defence Force, 2017); Vice Chief of Defence Force, Australia, *Future Operating Environment 2035* (Canberra: Commonwealth of Australia, 2016); and Canadian Department of National Defence, *Designing Canada's Army of Tomorrow: A Land Operations 2021 Publication* (Kingston, Canada: Directorate of Land Concepts and Designs, 2011).

5   For an examination of Russia's re-investment in conventional military capability, see Bettina Renz, "Why Russia is Reviving Its Conventional Military Power," *Parameters* 46, no. 2, Summer 2016.

6   The progress in developing sophisticated conventional forces, the modernization of equipment, and structural reform is charted in a series of unclassified Pentagon annual reports to the U.S. Congress. The most recent report in 2017 describes a range of initiatives to implement joint command and control systems, and a range of modernization activities. See Office of the Secretary of Defense (OSD), *Military and Security Developments Involving the People's Republic of China 2017*, Annual Report to Congress (Washington, DC: DoD, May 15, 2017), p. 31, available at https://www.defense.gov/Portals/1/Documents/pubs/2017_China_Military_Power_Report.PDF.

operations conducted by the large conventional forces of countries such as Russia, Iran, and China—but could also be employed by their proxies.

The Nature of Work

A second impact on ground forces will be substantial changes in global employment. Just as the industrial revolution changed the nature of work, the information age is resulting in large shifts in work and workforce design. Studies from academia and business think tanks have examined this issue, and the consensus is that global commerce is only just starting to capture the potential of digitizing economies and the impact of large-scale application of algorithms and automation.[7] Although robotics and "thinking machines" have been used commercially for some time, this is expected to accelerate in the next two decades.

This will affect both blue- and white-collar jobs. Manufacturing and high-speed financial trading have already been affected by robotics and AI. As AI continues to improve, industries such as transportation, healthcare, banking, and construction will see people displaced from their jobs, although experts disagree about the pace at which this will occur.[8]

This change in the global civilian labor market will eventually affect military personnel management models. New technologies will permit the automation of many tasks currently performed by soldiers. As automation and AI allow civilian business leaders to place humans in different kinds of work, so too will military personnel planners be forced to think anew about the recruiting and employment opportunities of a new global workforce approach. It is likely to drive the creation of new military personnel models and in turn the designing of new ground force structures. This, along with the disruptive technologies of robotics, AI, and human augmentation could enable new operating concepts.

The Disruptive Effect of Robotics, AI, and Augmentation

Contemporary robots and machine learning are already changing the nature of work in society and how we conceive shopping and entertainment. Advanced computing has changed the character of mass marketing, warehousing, civil logistics, and entertainment.[9] As the private sector drives these

---

[7]   See James Manyika, "Technology, Jobs, and the Future of Work," executive briefing, McKinsey Global Institute, May 2017, available at https://www.mckinsey.com/global-themes/employment-and-growth/technology-jobs-and-the-future-of-work.

[8]   Aaron Smith and Janna Anderson, *AI, Robotics, and the Future of Jobs* (Washington, DC: Pew Research Center, August 6, 2014), available at http://assets.pewresearch.org/wp-content/uploads/sites/14/2014/08/Future-of-AI-Robotics-and-Jobs.pdf.

[9]   For more on this topic, see Erik Brynjolfsson and Andrew McAfee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies* (New York: W. W. Norton & Company, 2016); and Andrew McAfee and Erik Brynjolfsson, *Machine, Platform, Crowd: Harnessing Our Digital Future* (New York: W. W. Norton & Company, 2017).

innovations for commercial advantage, military advances in robotics, AI, and augmentation will largely be based on these developments in industry.

Gill Pratt, former DARPA Program Manager and CEO of the Toyota Research Institute, has argued that technological and economic trends are converging to deliver a "Cambrian Explosion" of new robotic capabilities.[10] This is an analogy to the history of life on Earth, specifically the period roughly 500 million years ago in which the pace of evolutionary change, for both diversity and complexity of life forms, increased significantly. Many of the foundational technologies for robots, such as computing, data storage, and communications, have been progressing at exponential growth rates.

Two more recent technologies, Cloud Robotics and Deep Learning, are likely to build upon these earlier technologies in what Pratt has described as a "virtuous cycle of explosive growth."[11] Cloud Robotics permits each individual robot to learn from the experiences of all robots, in turn leading to rapid growth of robot competence. Deep Learning algorithms allow robots to learn and generalize their associations based on very large (and often cloud-based) training sets that often include millions of examples.[12]

Commerce currently leads the way for how robots and AI can be employed. For example, Amazon currently employs approximately 80,000 robots in its logistic distribution centers, known at Amazon as fulfillment centers.[13] Amazon also possesses its own robotics research and development capacity, known as Amazon Robotics.[14] The mining industry applies autonomous systems for many functions; Excavating and hauling vehicles have been equipped with vehicle controllers, high-precision global positioning system (GPS) sensors, and obstacle detection. These allow for safer operations through a complex load, haul, and dump cycle and enable integration with other vehicles and people.

These are just some of the lessons from commerce that the military can and should learn for its own employment of robotics and AI.[15] The applicability for these advancements in military support and combat operations should be obvious. This is not to say that ground forces are readily prepared to adapt these commercial models for military employment. Substantive adaptation is

---

[10]   Gill, A. Pratt, "Is a Cambrian Explosion Coming for Robotics?" *Journal of Economic Perspectives* 29, no. 3, Summer 2015, available at https://pubs.aeaweb.org/doi/pdf/10.1257/jep.29.3.51.

[11]   Ibid.

[12]   Ibid.

[13]   Casey Coombs, "Amazon to Spend $200M for One of its Most Expensive Fulfilment Centers Ever (Video)," *Puget Sound Business Journal*, June 9, 2017.

[14]   For more information on Amazon Robotics, visit https://www.amazonrobotics.com/#/.

[15]   Defense Science Board, Office of the Under Secretary of Defense (OUSD), *Summer Study on Autonomy* (Washington, DC: DoD, June 2016), p. 8, available at https://www.hsdl.org/?view&did=794641.

required of the technologies and the military organizations employing them is required before the full benefits of automation can be realized.

Implications for Future Ground Forces

In addition to future geopolitical changes and new global approaches to workforce structures, the potential applications of robotics and AI will also drive their military employment. The six propositions below describe the key drivers for ground forces to develop their future human-machine organizations.

1. **Teaming humans with robotic and AI capabilities can boost national military power.** The effects of robot/AI and military teaming could be seen as a force multiplier in aspects of military capacity and strategic planning capability.

   The number of combat-age males in a country is one of the elements that determine its military potential. By using large numbers of robots, augmented humans, and AI, countries with small, elderly, and declining populations might possess military mass beyond their human population size. Although such a scenario is speculative, it is possible that a technologically advanced country with a smaller population could build a significant advantage using AI-based military systems and fielding large numbers of robotic warfighters. This could also provide a deterrent effect for these nations' national security strategies.[16]

   The use of AI by policymakers and military planners in decision support may also offer advantages at the strategic level. AI can assess large amounts of data, challenge human bias, and recognize patterns that humans may not comprehend. Although it will present ethical and technical issues, the marriage of humans and AI in strategic decision-making will have wide utility.

2. **Teaming humans with robots and AI will improve individual and team performance while reducing threats to humans.** Augmenting human capabilities potentially offers additional gains in performance and reductions in threats. The science and technologies underwriting human enhancements are advancing quickly.[17] Unlike the mechanical approach of robotics, augmentation seeks to create a super-soldier from a biomedical direction, such as with drugs and bionics. As Lin and Abney have noted, "In between robotics and biomedical research, we might arrive at the perfect future warfighter:

---

16   The issue of deterrence in a non-nuclear military organization is covered only briefly in the most recent military strategy for Australia, described in its Defence White Paper. The only capability which is explicitly described as a deterrent are submarines. See Department of Defence, Australia, *Defence White Paper 2016* (Canberra: Commonwealth of Australia, 2016), especially p. 90.

17   Patrick Lin, Maxwell J. Mehlman, and Keith Abney, *Enhanced Warfighters: Risk, Ethics, and Policy* (San Luis Obispo, CA: California Polytechnic State University, January 1, 2013), p. 86, available at http://ethics.calpoly.edu/greenwall_report.pdf.

one that is part machine and part human, striking a formidable balance between technology and our frailties."[18]

3. **Robots and AI can enable new operating concepts.** The new and interdisciplinary research areas of AI, complex adaptive systems, and swarm optimization indicates the potential for self-organized robot swarms to be used in future conflict.[19] As conventional enemy forces move to lower signature systems and operations, and as non-state actors continue to hone non-linear and dispersed approaches,[20] the ability to cover more ground becomes more challenging.[21] One potential solution for friendly forces, described by Robert Scales in *Future Warfare Anthology,* is to saturate an operational area with small autonomous systems that force an adversary to move, be detected, and be targeted by friendly forces.[22] From an institutional perspective, new operating concepts are vital in building a competitive edge. This does not suggest that swarming become the only means of operating, but it does offer additional options to military commanders within joint operations.

Even if friendly forces do not employ swarming, they will have to protect themselves against hostile swarming approaches. Allied ground forces possess thousands of land vehicles and helicopters. A high-quality quadcopter UAV currently costs roughly $1,000. In consequence, for the cost of a single helicopter, a ground force might acquire tens of thousands of drones. In the future, drones could be cheaper than some ballistic munitions today. How would a ground force embarked on an amphibious task group respond to an attack from hundreds of aerial

---

[18]   Ibid., p. 87.

[19]   The opportunities and challenges of swarming robots is examined in detail in Andrew Ilachinski, *AI, Robots, and Swarms: Issues, Questions, and Recommended Studies* (Arlington, VA: CNA, January 2017), pp. 105–131, available at https://www.cna.org/CNA_files/PDF/DRM-2017-U-014796-Final.pdf; Sean J. A. Edwards, *Swarming and the Future of Warfare*, Pardee RAND Graduate School dissertation (Santa Monica, CA: RAND corporation, 2005), available at https://www.rand.org/content/dam/rand/pubs/rgs_dissertations/2005/RAND_RGSD189.pdf; and Jules Hurst, "Robotic Swarms in Offensive Maneuver," *Joint Forces Quarterly* 87, October 2017, pp. 105–111, available at http://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-87/jfq-87_105-111_Hurst.pdf?ver=2017-09-28-093018-793.

[20]   The trend toward a more dispersed battlespace (physically but also including aspects such as cyberspace) has been identified in multiple studies and publications over the past two decades. These include Trevor Nevitt Dupuy, *The Evolution of Weapons and Warfare*, first printing (Indianapolis, IN: Bobbs-Merrill Co., 1981); Robert H. Scales Jr., *Future Warfare Anthology* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, May 2001); Brian Nichiporuk and Carl H. Builder, *Information Technologies and the Future of Land Warfare* (Santa Monica, CA: RAND Corporation Arroyo Center, 1995); Directorate of Army Research and Analysis, *Complex Warfighting* (Canberra: Australian Army Headquarters, September 2009), p. 17; Andrew F. Krepinevich and Eric Lindsey, *The Road Ahead: Future Challenges and their Implications for Ground Vehicle Modernization* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012), p. 18; and U.S. Army, *The U.S. Army Operating Concept: Win in a Complex World 2020–2040* (Fort Monroe, VA: TRADOC, October 31, 2014), pp. 10–11.

[21]   Edwards, *Swarming and the Future of Warfare*, pp. 7–12.

[22]   Scales, *Future Warfare Anthology*, p. 82.

explosive drones? Some of the major platforms and strategies upon which current military forces rely might be rendered obsolete, or at least highly vulnerable. [23]

4. **Military forces could employ robots on future military operations as an ethical preference.** Some experts in robotics have argued that lethal autonomous robots may be ethically preferable to human fighters. One compelling argument is that wider use of robots holds the potential to reduce the number of humans killed in conflict. It is possible that future autonomous robots will be able to act more "humanely" on the battlefield for a number of reasons, including that they do not need to be programmed with a self-preservation instinct and will not require a "shoot first, ask questions later" approach. [24] The judgment of robots is unlikely to be affected by emotions such as fear or hysteria, and they are likely to be able to process more incoming sensory information than humans without discarding or distorting it to fit preconceived notions. [25]

5. **Future adversaries will use these technologies.** These technologies are highly attractive to other national military organizations[26] and non-state actors. There is a proliferation of unmanned capability around the world in national armed services with nearly 80 nations either developing or deploying these systems. [27] The Russian Military Industrial Committee has approved a plan that would have 30 percent of Russian combat power consist of entirely remotely controlled and autonomous robotic platforms by 2030. [28] Other countries facing demographic and security challenges are likely to set similar goals. And although the U. S. Department of Defense has enacted restrictions on the use of autonomous and semi-autonomous systems wielding lethal force,[29] hostile nations and non-state actors may not exercise such self-restraint.

---

[23] Greg Allen and Taniel Chan, *Artificial Intelligence and National Security* (Cambridge, MA: Belfer Center for Science and International Affairs, July 2017), pp. 21–22.

[24] Ronald C. Arkin, "The Case for Ethical Autonomy in Unmanned Systems," *Journal of Military Ethics* 9, no. 4, 2010; and Ronald C. Arkin, "Ethical Robots in Warfare," *IEEE Technology and Society Magazine* 28, no. 1, Spring 2009.

[25] These issues are examined in Amitai Etzioni and Oren Etzioni, "Pros and Cons of Autonomous Weapons Systems," *Military Review*, May-June 2017, available at http://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/May-June-2017/Pros-and-Cons-of-Autonomous-Weapons-Systems/.

[26] The use of unmanned systems by adversaries is an assumption in U.S. Army, *Multi-Domain Battle: Evolution of Combined Arms for the 21st Century 2025–2040*, Draft Version 1.0 (U.S. Army, October 2017).

[27] P. W. Singer, "The Global Swarm," *Foreign Policy*, March 11, 2013, available at http://foreignpolicy.com/2013/03/11/the-global-swarm/.

[28] Samuel Bendett, "Get Ready, NATO: Russia's New Killer Robots are Nearly Ready for War," *The Buzz*, blog, The National Interest, March 7, 2017.

[29] DoD, "Autonomy in Weapon Systems," Department of Defense Directive 3000.09, November 21, 2012.

In its Mosul operations of 2017, ISIS deployed a range of lethal unmanned ground and air vehicles.[30] Russian forces have used unmanned ground and aerial vehicles in their operations in Syria,[31] and they have used unmanned aerial vehicles extensively in the Ukraine.[32] No existing ethical or legal framework, or international counter-proliferation framework, prevents this.

In comparison to more expensive conventional capabilities, the low cost and accessibility of robotics and AI make them highly attractive. As Brecher, Niemi, and Hill have recently written, "Our adversaries care about the morals and ethics of lethal, autonomous systems only insofar as those concerns give them a competitive advantage. If full autonomy gives them supremacy on the battlefield, they will care little about what human rights lawyers think."[33]

6. **Robots and AI can improve all institutional and support functions of ground forces.** The broad potential applicability of these systems means that ground forces should adopt an enterprise approach to the employment of human-machine teams. Human-robot teams can be used in training institutions, freeing up personnel to be re-deployed for other operations. Advanced computing and analytical capacity may well be very useful in human-AI strategic decision-making teams for capability development, resource allocation, and talent management of personnel. Cognitive augmentation may be as useful for decision-makers at a strategic headquarters as it is for soldiers deployed on operations.

---

[30] The Battle of Mosul has been examined in multiple publications. Examples include "The Battle for Mosul," *Strategic Comments* 23, no. 4, May 17, 2017; Gary Volesky and Roger Noble, "Theatre Land Operations: Relevant Observations and Lessons from the Combined Joint Land Force Experience in Iraq," *Military Review*, June 22, 2017; and Australian Army, "Immediate Lessons from the Battle of Mosul," *Land Power Forum*, June 25, 2007, available at https://www.army.gov.au/our-future/blog/land-combat/immediate-lessons-from-the-battle-of-mosul.

[31] Patrick Tucker, "Armed Ground Robots Could Join the Ukrainian Conflict Next Year," *Defense One*, October 10, 2017, available at http://www.defenseone.com/technology/2017/10/armed-ground-robots-could-make-their-combat-debut-ukrainian-conflict-next-year/141677/?oref=d-river.

[32] Patrick Tucker, "In Ukraine, Tomorrow's Drone War is Alive Today," *Defense One,* March 9, 2015, available at http://www.defenseone.com/technology/2015/03/ukraine-tomorrows-drone-war-alive-today/107085/?oref=search_drone%20war%20ukraine.

[33] Joseph Brecher, Heath Niemi, and Andrew Hill, "My Droneski Just Ate Your Ethics," *War on the Rocks*, August 10, 2016, available at https://warontherocks.com/2016/08/my-droneski-just-ate-your-ethics/.

Closing Thoughts

As these technologies continue to develop, additional imperatives—beyond these six propositions—are like to emerge. Civil and military organizations are still learning about the potential of robotic systems and AI. Andrew Ilachinski has recently noted:

> the military is on the cusp of a major technological revolution as it enters the Robotic Age, in which warfare is conducted by unmanned and increasingly autonomous weapon systems, operating across all domains (air, sea, undersea, land, space, and cyber), and across the full spectrum of military operations. The question is not whether the future of warfare will be filled with autonomous, AI-driven robots, but when and in what form.[34]

The barriers for entry for this type of technology are lower than many other types of conventional weapons and continue to fall. This is an advantage for conventional and non-state military organizations, large and small.[35]

---

[34] Ilachinski, *AI, Robots, and Swarms*, p. 231.

[35] See Itai Barsade and Michael C. Horowitz, "Militant Groups Have Drones. Now What?" *Bulletin of Atomic Scientists*, September 7, 2017, available at http://thebulletin.org/militant-groups-have-drones-now-what11089.

Chapter 2

Future Human-Machine Teams: Three Key Endeavors

Chapter I of this report explored a rationale for enterprise-wide adoption of human-machine teams in ground forces. It is proposed that three human-machine endeavors will underpin the development of future human-machine ground forces. Each is a distinct area of research, development, and investment.

1. **Human-robot teaming.** [36] This focuses on human-robot partnerships and organizational learning about how humans interact with robotic partners. It will involve development of the capacity for humans to supervise and task large robot teams and interact with robotic teammates. This will require contributions from several related disciplines, such as systems engineering, cognitive sciences, and computer sciences. [37]

2. **Teaming humans and AI**. Most teams are likely to contain increasingly sophisticated types of AI. The marriage of humans and AI for strategic and operational planning, as well as for the analysis of future activities, are key applications. This requires analytical focus that is related to, but distinct from, human-robot teaming.

3. **Human augmentation.** This mode of human-machine teaming is distinct from the other two because humans and machines are combined as a single entity. It is focused on improving

---

[36] Current examples of the types of robotic systems that are teamed with humans include explosive ordnance disposal robots, aerial drones, and the seaborne Sea Knight surface patrol vessel. The Sea Knight is an unmanned sea patrol vessel developed by Israel.

[37] Pierre Urlings, *Teaming Human and Machine: A Conceptual Framework for Automation from and Aeronautical Perspective*, thesis (Adelaide: University of South Australia, December 2003), p. 84.

human performance—physical and cognitive—using mechanical, wearable, and implantable capabilities that enhance existing human capacity.

These three endeavors should be pursued concurrently.[38] The basic technology for each already exists. Concurrent development would allow program interaction and would significantly improve the deployability, lethality, and sustainability of future ground forces.

Human-Robot Teaming

In his 2009 book, *Wired for War,* Peter Singer examined the future of warfare with robots becoming a pervasive element of military operations. This is not a new vision. Science fiction writers have been writing about robots in warfare for nearly a century. Indeed, human automata have been described and constructed for over 500 years. But it was only in 1921 that the Czech writer Karel Čapek coined the term "Robot" in a play called *Rossum's Universal Robots.*[39] Scientists, writers and industrialists have built and imagined robots for a wide range of functions. From models for assembly line construction of motor vehicles to the more sophisticated models employed on the International Space Station[40], early generation robots have assumed functions that are either cheaper or safer than using humans.

A number of reports have described how robotic systems are likely to proliferate over the next 20 years.[41] As they become cheaper and easier to produce, these technologically advanced systems are likely to be used widely, with developing states and non-state actors gaining increased access to

---

[38] Recent U.S. military efforts have focused on five lines of endeavor: Autonomous deep learning systems; human-machine collaboration; assisted human operations; advanced human-machine combat teaming; and network-enabled cyber-hardened autonomous weapons. See remarks by Deputy Secretary of Defense Robert Work at the Center for New American Security Defense Forum, December 14, 2015, quoted in George Galdorisi, "Designing Unmanned Systems for Military Use: Harnessing Artificial Intelligence to Provide Augmented Intelligence," *Small Wars Journal,* August 23, 2017 available at http://smallwarsjournal.com/jrnl/art/designing-unmanned-systems-for-military-use-harnessing-artificial-intelligence-to-provide-a.

[39] Karel Čapek, *R.U.R. (Rossumovi Univerzální Roboti)* (written 1920), Paul Selver, trans., *Rossum's Universal Robots* (London: Oxford University Press, 1923).

[40] Evan Ackerman, "Astrobee: NASA's Newest Robot for the International Space Station," *IEEE Spectrum* (online), February 11, 2017, available at http://spectrum.ieee.org/video/robotics/military-robots/astrobee-nasa-newest-robot-for-the-international-space-station.

[41] A selection of publications that have examined this trend include: MOD UK, *Future Operating Environment 2035*, p. 32; U.S. Army, *Robotic and Autonomous Systems Strategy*; Australian Army, Directorate of Future Land Warfare, *Future Land Warfare Report* (2014); and U.S. Army, *The Operational Environment and the Changing Character of Warfare* (Fort Monroe, VA: TRADOC, 2017). See also The Atlantic Council's Art of the Future project, available at http://artoffuturewarfare.org/; and the World Economic Forum's project on the relationship between the Fourth Industrial Revolution and International Security, summarized in Anja Kaspersen, Espen Barth Eide, and Philip Shetler-Jones, "10 Trends for the Future of Warfare," *World Economic Council*, November 3, 2016, available at https://www.weforum.org/agenda/2016/11/the-4th-industrial-revolution-and-international-security/.

them. As they become more capable, more reliable, and more trusted by humans, their employment in all military services is likely to become widespread.[42]

Robots in human-robot teams are likely to possess varying levels of autonomy. In their 2015 paper, *An Introduction to Autonomy in Weapon Systems*,[43] Horowitz and Scharre offer useful definitions of autonomous, semi-autonomous, and human-supervised autonomous weapon systems. As shown below, these definitions could be applied to the various levels of autonomy that humans might delegate to robots:

- A **human-supervised robot** has the characteristics of an autonomous robot system, but with the ability for human operators to monitor its performance and intervene to halt its operation, if necessary.

- A **semi-autonomous robot** is a one that incorporates autonomy into one or more functions and, once activated, is intended to only undertake those tasks that a human has decided are to be undertaken.[44]

- An **autonomous robot** is one that, once activated, is intended to undertake tasks not specifically tasked by humans. In the case of lethal robots, they might select and engage targets where a human has not decided those specific targets are to be engaged.

The military has long held an interest in robotic capability. Remote controlled boats were used by the Germans in the First World War. In the Second World War, the Germans employed unmanned, Goliath tracked vehicle robots filled with explosives in France and Italy. More recently, at the high point of the Iraq War in 2006, over 8,000 robots were in use by the U.S. military.[45]

Enterprise and Battlefield Applications

Human-robot teams have application across a range of ground force missions. In an enterprise approach, human-robot combinations would be useful in training establishments to improve training outcomes and provide the testbed for best practice in developing human-robot tasking

---

[42]   MOD UK, *Future Operating Environment 2035*, p. 16.

[43]   Paul Scharre and Michael C. Horowitz, *An Introduction to Autonomy in Weapon Systems*, working paper (Washington, DC: Center for a New American Security, February 2015), available at https://s3.amazonaws.com/files.cnas.org/documents/Ethical-Autonomy-Working-Paper_021015_v02.pdf.

[44]   Ibid., p. 16.

[45]   P. W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, reprint edition (New York: Penguin Press, 2009), p. 32.

relationships. In logistics, robots will have utility in performing tasks that are dirty, dangerous, or repetitive (such as vehicle maintenance and repair and basic movement tasks).[46]

In addition to the better known unmanned aerial vehicle programs, there are many robotic ground systems either in development or being deployed with military organizations. Since 2004, the Defense Advanced Research Project Agency has held "DARPA challenge" competitions to encourage the development and capabilities of unmanned ground vehicles.[47] Companies such as Lockheed Martin have developed a range of autonomous vehicles for logistics at different levels. This has included small squad-level unmanned ground vehicles to support larger autonomous heavy trucks.[48]

The use of human-robot teams during operations offers a solution to an enduring challenge for ground forces—the building of mass. Potentially, each soldier might control a small fleet of ground and air systems, providing an exponential increase in the capability of deployed forces. A 2016 U.S. Department of Defense experiment saw over 100 micro drones released to form an autonomous swarm.[49] If swarming concepts were embraced as one aspect of ground force operational design, future land vehicle "carriers" might fill similar "mothership" roles.

A highly capable and sustainable land combat battlegroup in 2030 may consist of as few as 250–300 human soldiers and several thousand robotic systems of various sizes and functions. By the same token, many functions of artillery and combat engineer units, currently undertaken by humans, might be better done by robots in human-robot teams. This has the potential to reduce the size of these types of units by hundreds of combat arms personnel. This approach could free up personnel for redeployment into areas where the art of war demands leadership and creativity— enabling intelligence functions; training and education; planning; and, most importantly, command and leadership.

For ground forces, human-robot teaming could provide the core for all future ground force design. Select high-priority, focal areas of human-robot teaming might be chosen to provide benchmarks

---

[46]   This idea of employing robots for the "dirty, dangerous, and dull" tasks is examined in Max Boot, *War Made New: Technology, Warfare, and the Course of History: 1500 to Today* (New York: Gotham Books, 2006), p. 442.

[47]   This effort has recently emphasized safer vehicles and more assured autonomy. "DARPA Assured Autonomy Seeks to Guarantee Sargent of Learning-Enabled Autonomous Systems," DARPA website, August 16, 2017, available at https://www.darpa.mil/news-events/2017-08-16.

[48]   The Lockheed Martin Website has detailed information on their unmanned ground vehicle programs available at http://www.lockheedmartin.com.au/us/products/amas1.html.

[49]   The Strategic Capabilities Office, partnering with Naval Air Systems Command, demonstrated the micro-drone swarms at China Lake, California. The test, conducted in October 2016 and documented on Sunday's CBS News program "60 Minutes," comprised 103 Perdix drones launched from three F/A-18 Super Hornets. The micro-drones demonstrated advanced swarm behaviors such as collective decision-making, adaptive formation flying, and self-healing. "Department of Defense Announces Successful Micro-Drone Demonstration," DoD media release, January 9, 2017, available at https://www.defense.gov/News/News-Releases/News-Release-View/Article/1044811/department-of-defense-announces-successful-micro-drone-demonstration/.

for driving and measuring progress. Potential focal areas might include the ISR battle, breach and break action, and close combat. These are activities that are demanding in the integration of various ground and joint functions. Initial experiments in these three areas would focus on simple human-robot integration activities. Subsequent experiments could expand in scope to include human-AI integration and human augmentation. This is explored further in Chapter IV.

Human-AI Teaming

In 1899, diplomats from the world's leading military powers convened in The Hague for a peace conference. One of the outcomes of the conference was a five-year moratorium on all offensive military uses of aircraft. Although the intention was to later make the ban permanent, it was abandoned at the second Hague conference of 1907 once countries saw the irresistible potential of aerial warfare.[50] Aerospace technology eventually became nearly synonymous with military power. It is likely that the use of AI will chart a similar course. Businesses are choosing machine learning because competitively they have no choice; so, too, will militaries and intelligence agencies feel competitive pressure to expand the use of military AI applications.[51]

Key to human-AI teaming is understanding the increasing pace and complexity of decision support and decision-making. In future conflicts, military organizations will work across "multiple domains with multiple partners, considering multiple dilemmas and options."[52] Decision cycles will ultimately become faster than the capacity of human cognition to process.[53]

In this environment, military command and control will need AI that can process information and recommend options faster (or of higher quality) for making decisions than can the enemy. There are three primary areas in which AI might be applied in this context:

- **Assisted intelligence**, widely available today, improves what people and organizations are already doing. A simple example is the GPS navigation programs in vehicles and aircraft that offer directions to drivers and aircrew.

---

[50] Allen and Chan, *Artificial Intelligence and National Security*, p. 50.

[51] Ibid., p. 50.

[52] U.S. Army, *The U.S. Army Operating Concept: Win in a Complex World 2020–2040*, pp. iii–iv.

[53] This issue is examined in a range of publications related to future conflict. It is examined in MOD UK, *Global Strategic Trends—Out to 2045*, and the U.S. Army Operating Concept describes this as "increased velocity and momentum of human interaction and events." U.S. Army, *The U.S. Army Operating Concept: Win in a Complex World 2020–2040*, p. 11.

- **Augmented intelligence**, which is emerging today, helps people and organizations to do things they couldn't otherwise do. The rapid engagement capability of a naval CIWS is an example.

- **Autonomous intelligence**, being developed for future applications, establishes machines that act on their own. An example of this will be self-driving vehicles when they come into widespread use.[54]

There is a wide debate among leading AI researchers about whether **human-level AI** is possible and when it might appear. The nearest estimates are "in a few decades" with other experts predicting "not this century" and even "not ever."[55] This timeline for human-level AI prevents against anything other than speculation when thinking about and planning for military capability development. But scientists and experts have been wrong about the pace of scientific discovery in the past. In 1933, Ernest Rutherford, one of the great nuclear scientists of his time, stated that nuclear energy was "moonshine." And in 1956, Astronomer Royal Richard Woolley described discussions on space travel as "utter bilge."[56] So, it is possible that human-level AI may appear sooner than anticipated. But for the purposes of this study, it is given less focus than assisted, augmented, and autonomous intelligence.

Partially autonomous and intelligent systems have been used by military organizations since the Second World War. However, advances in machine learning and AI represent a turning point in the use of automation in warfare.[57] This is a field where rapid advances will provide opportunities for military organizations to re-think the conduct of planning, information gathering and analysis, cyber security, logistics, and strategy development in war.

A key driver for the use of AI in warfare is the convergence of large numbers of advanced sensors, extensive communication links, and an ever-increasing flow of information. As the quantity of information continues to increase, the capacity of humans to deal with it is not increasing in a commensurate manner. The slowest element in decision-making is becoming the human decision-maker. In the competitive environment of war, the race truly does go to the swift.[58]

---

[54] "Workforce of the Future: The Competing Forces Shaping 2030," Price Waterhouse Coopers slide presentation, 2017, available at https://www.pwc.com/gx/en/services/people-organisation/workforce-of-the-future/workforce-of-the-future-the-competing-forces-shaping-2030-pwc.pdf.

[55] For discussion on the potential timelines for human level AI, see Max Tegmark, *Life 3.0: Being Human in the Age of Artificial Intelligence* (New York: Alfred A. Knopf publishing, 2017), pp. 30–40.

[56] Ibid., p. 40.

[57] Allen and Chan, *Artificial Intelligence and National Security*, p. 5.

[58] Richard Simpkin was one of the first authors to write about the implications of command and control in the 21st century. While he wrote several books on various aspects of war, his 1985 book *Race to Swift* remains one of the best examinations of decision-

Developments in the civilian sector provide insights into potential military applications. Microsoft's *Cortana*, Google's *Now*, Amazon's shopping sites, Netflix's streaming algorithms, and Apple's *Siri* all combine user input, access to large databases, and *limited AI* algorithms to provide decision support for human users. These provide individually tailored options based an individual's previous decisions, as well as those of millions of other users. It represents a slow and steady shift of authority from humans to algorithms.[59] Although there are pitfalls in this for the unwary, it also offers the potential benefit to the military of more rapid decision-making in complex circumstances.

Despite the speed and analytical capacity of computers and robots, creativity or imagination remains a challenge for AI.[60] Advances in this area have been made, however; AI systems have recently created songs and movie trailers.[61] This rapid advance in AI research and development has the potential to result in new and disruptive innovations in the planning and conduct of military operations.[62]

The U.S. Department of Defense, in a study of the future operating environment, has recently described artificial intelligence as "the most disruptive technology of our time. Big data techniques interrogate massive databases to discover hidden patterns and correlations and are continually leveraged for intelligence and security purposes by nation states and non-state entities alike."[63] Efforts by institutions such as the United Nations and the Future of Life Institute[64] to impose a moratorium on the use of AI in weapons are unlikely to succeed. As Ian Morris wrote in 2014,

---

making, speed, and 21st century warfare. Richard Simpkin, *Race to the Swift: Thoughts on Twenty-first Century Warfare* (London: Brasseys, 1985).

[59] In his book *Homo Deus*, Yuval Norah Harari conducts a detailed examination of the biological and technical aspects of these trends. He notes that "the shifting of authority from humans to algorithms is happening all around us, not as a result of some momentous governmental decision, but due to a flood of mundane personal choices." Yuval Norah Harari, *Homo Deus: A Brief History of Tomorrow* (London: Vintage Books, 2015), p. 402.

[60] There are three types of creativity: novel combinations of familiar ideas, generation of new ideas by exploring structured conceptual spaces, and generation of new and surprising ideas. Computer models do exist of creativity. Generally, those focused on exploratory creativity have been most successful. Margaret A. Boden, "Creativity and Artificial Intelligence," *Artificial Intelligence*, no. 103, 1998.

[61] "The Quest for AI Creativity," IBM, available at https://www.ibm.com/watson/advantage-reports/future-of-artificial-intelligence/ai-creativity.html#section2.

[62] See George I. Seffers, "Commanding the Future Mission," *Signal*, May 2016; James Canton, "Next-Gen Computers Will Soon Transform Battlefield Intelligence," *National Defense Magazine*, February 2017.

[63] U.S. Army, *The Operational Environment and the Changing Character of Warfare*, pp. 8–9.

[64] The most recent call for a ban on "killer robots" was issued by top robotics and AI companies through a letter posted on the "Future of Life Institute" website on August 20, 2017. Ariel Conn, "Leaders of Top Robotics and AI Companies Call for Ban on Killer Robots," Future of Life Institute news, August 20, 2017, available at https://futureoflife.org/2017/08/20/leaders-top-robotics-ai-companies-call-ban-killer-robots/.

"When robots with OODA loops[65] of nanoseconds start killing humans with OODA loops of milliseconds, there will be no more debate."[66] Weapons and other artifacts of war will incorporate AI because military organizations will fear if they do not, their enemies will.[67]

Enterprise and Battlefield Applications

Human-AI teams will have broad applications in military organizations. The recent establishment of an Algorithmic Warfare Cross-Functional Team[68] by the U.S. Deputy Secretary of Defense is one recognition of the potential application of AI in strategic-level Headquarters. In an enterprise approach, human-AI combinations would be useful in providing support to strategic analysis and decision-making. This will have applications in strategic intelligence agencies, particularly for processing, exploitation, and dissemination; complex big data analysis; network modelling; and targeting. It will also be vital for cyber applications such as network intelligence and intrusion detection.

Modeling different equipment procurement options is another example of where human-AI teams may prove more effective than human decision-making. Identifying leaner (and less targetable) approaches to logistics are also possible. Other strategic functions, including talent management, and personnel administration could be improved through the development of human-AI teams that can sift data and undertake analysis with less heuristic bias.

By teaming human decision-makers with AI that can collate and present meaningful information, military leaders may be able to establish decision superiority over an adversary—assuming that adversary is not using similar systems. But even if there is a suitable marriage of humans and AI, the speed at which AI is developing means that more functions will move beyond human comprehension and may have to be delegated to autonomous systems out of necessity.[69]

---

[65] The OODA Loop—Observe, Orient, Decide, Act—was developed by U.S. military officer John Boyd based on his observations of competitive behavior and time cycles. Grant T. Hammond, *The Mind of War: John Boyd and American Security* (Washington, DC: Smithsonian Institution Press, 2001).

[66] Ian Morris, *War: What Is It Good For?* (London: Profile Books, 2014), p. 374.

[67] For example, one driver for the United States military will likely be the embrace of AI by its main strategic competitor, China. On July 20, 2017, China released its Artificial Intelligence strategy called *A Next Generation Artificial Intelligence Plan*. The original version can be found at http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm. The translated version of the strategy can be found at https://www.newamerica.org/documents/1959/translation-fulltext-8.1.17.pdf.

[68] Deputy Secretary of Defense, "Establishment of an Algorithmic Warfare Cross-Functional Team (Project Maven)," memorandum, April 26, 2017, available at https://www.govexec.com/media/gbc/docs/pdfs_edit/establishment_of_the_awcft_project_maven.pdf.

[69] Thomas K. Adams, "Future Warfare and the Decline of Human Decision-making," *Parameters*, Winter 2001–2002. This rapid progress in the development of AI has four main drivers: first, the exponential growth in computer performance; second, the improved access to large datasets that can be used to train machine learning systems; third, continuing advances in machine learning techniques; and, finally, rapidly increasing commercial investment in AI. Allen and Chan, *Artificial Intelligence and National Security*, p. 7.

During operations, the provision of sophisticated AI decision support has potential to assist tired planners in military headquarters. This might have applications at all levels of command—from a battlegroup headquarters analyzing and wargaming various tactical options to a strategic-level headquarters modelling optimal application of kinetic and non-kinetic activities and logistic support. AI offers the potential to automate functions such as routine resupply,[70] network management, and movement schedules. Importantly, AI embedded in autonomous and semi-autonomous systems offers rapid responses to the actions of an adversary, should these systems be trusted by their human operators.

Ultimately, the speed at which autonomous systems function may force humans to operate further up the chain of command. As Adams notes, tactical warfare may become the business of machines and not appropriate for people at all.[71] But if war is to remain a human activity, and we assume that war's nature is enduring, humans will still play a role in policy, strategy, and campaigning.

Human Augmentation

The augmentation of humans is likely to represent the ultimate expression of the human-machine revolution. This is an extension of centuries of practice where people sought to become faster, stronger, and smarter by using tools and machines. It is useful to look at contemporary human augmentation efforts to project future capabilities in this area.

The U.S. military has been a major investor in this field, leading a variety of research projects that seek to optimize human fighting capacities. DARPA's Accelerated Learning program, for example, seeks to apply the best practices of learning as demonstrated by neuroscience and statistical modelling.[72] There are three approaches to human augmentation applicable to the military: wearable computing augmentation, mechanical augmentation, and implantable augmentation.

Wearable Computing Augmentation

Wearable computing incorporates miniature body-borne computing and sensory devices that are worn under, over, or in clothing. More recently it has included smart clothing and other wearable devices such as glasses.[73] The age of wearable computing commenced when mathematicians Edward Thorp and Claude Shannon built computerized timing devices, hidden in their shoes, to

---

[70] Noting the likelihood of a more dispersed and lethal battlefield in the future, this approach is examined in Krepinevich and Lindsey, *The Road Ahead*, pp. 50–51.

[71] Adams, *Future Warfare and the Decline of Human Decision-making*, pp. 70–71.

[72] "DARPA's Accelerated Learning," tDCSPlacements.com, available at http://tdcsplacements.com/placements/accelerated-learning/.

[73] Smita Jhajharia et al., "Wearable Computing and its Application," *International Journal of Computer Science and Information Technologies* 5, no. 4, 2014, p. 5700.

assist them to win a game of roulette in 1961.[74] Wearable computing now includes augmented and virtual reality devices, as well as the wide range of watch-like devices including products from Apple, Samsung,[75] and Fitbit.[76] The commercial market for smart wearable devices such as smart watches, smart glasses, and wearable scanners is estimated to gross more than U.S. $60 billion by 2022.[77] The civil demand for such devices is driving rapid growth in research, development, and innovation in this field. This will underpin development of wearables for military purposes.

Wearable computing in the military has been led by the efforts of the United States Army. Launched in 1994, the Land Warrior program currently integrates wireless LAN, helmet-mounted displays, communications, and a soldier control system.[78] Many ground forces now possess, or are about to deploy, wearable computing capabilities. Functions normally deployed in wearable computing systems include navigation, communications, tactical information, and reporting. Future developments are likely to include the linking of weapon sensors and sights into wearable computers as well as the incorporation of biometric functions monitoring.[79]

Mechanical Augmentation

Humans have used simple mechanical augmentation such as artificial limbs for centuries. However, this field has received revived attention over the past two decades with many amputees returning from military operations in Iraq and Afghanistan. This has driven advances in the development of more sophisticated artificial limbs. Concurrently, this has re-energized interest in more complex mechanical augmentation with systems such as exoskeletons.

Several research organizations are developing exoskeletons to increase human strength and endurance. Examples for military use include Lockheed Martin's HULC,[80] Raytheon's XOS,[81] and

[74]   Steve Mann, "Wearable Computing," in Mads Soegaard and Rikke Friis Dam, eds., *The Encyclopedia of Human-Computer Interaction*, 2nd edition (Aarhus, Denmark: The Interaction Design Foundation, 2013), available at https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/wearable-computing.

[75]   Samsung currently offers several wearable products; see http://www.samsung.com/au/wearables/gear-s2/features/.

[76]   Fitbit offers a large range of fitness-oriented wearable devices; see https://www.fitbit.com/au/home.

[77]   "ABI Research Forecasts Enterprise Wearables Will Top US$60 Billion in Revenue in 2022," press release, ABI Research, August 10, 2017, available at https://www.abiresearch.com/press/abi-research-forecasts-enterprise-wearables-will/.

[78]   "Land Warrior Integrated Soldier System," Army Technology.com, available at http://www.army-technology.com/projects/land_warrior/.

[79]   Jhajharia, "Wearable Computing and its Application," p. 5702.

[80]   Additional information on the HULC exoskeleton is available at http://www.lockheedmartin.com.au/content/dam/lockheed/data/mfc/pc/hulc/mfc-hulc-pc-01.pdf.

[81]   Additional information about Raytheon's XOS project is available at http://newatlas.com/raytheon-significantly-progresses-exoskeleton-design/16479/.

the University of California Berkeley's BLEEX.[82] These exoskeletons are likely to offer a range of enhanced operational and training functions for ground forces.

The U.S. Army has funded multiple research programs in this field,[83] including USSOCOM's TALOS program.[84] Other nations have also developed combat suits that rely on exoskeleton technology. The Russian military reportedly deployed its *Ratnik* (Warrior) suit in Crimea as early as 2013. The 3rd generation suit, *Ratnik 3,* was announced by its designers on October 10, 2017, and it contains a range of sub-systems including communications, life support, engagement aides, and advanced optics.[85]

Implantable Augmentation

Implantables—small devices that humans can have implanted in their bodies—are already available for multiple functions. Cochlear implants have been available for over a decade to return hearing to the profoundly deaf.[86] Cardiac pacemakers are another example of our longstanding acceptance of implanting small machines into human bodies for medical reasons. And while medical technology will continue to be an important driver in this field, convenience also provides motivation.

In Australia this year, a Sydney man had the chip from an Opal travel card implanted to make traveling on public transport more convenient.[87] A Swedish company called *Epicenter* offers implants the size of a grain of rice to its workers that function as swipe cards to open doors, operate printers, or buy drinks with a wave of the hand.[88] Over the next decade, developments in implantables may include implantable smart phones, self-healing devices, smart pills for medical diagnosis, and readable smart tattoos.

---

[82] Additional information about the University of California Berkeley's BLEEX project is available at http://bleex.me.berkeley.edu/research/exoskeleton/bleex/.

[83] One insightful review of the various U.S. Army programs is Annie Jacobsen, "Engineering Humans for War," *The Atlantic*, September 23, 2015, available at https://www.theatlantic.com/international/archive/2015/09/military-technology-pentagon-robots/406786/.

[84] "Current Iterations of TALOS," information briefing, U.S. Special Operations Command, Tactical Assault Light Operator Suit (TALOS) Program Office, May 28, 2014.

[85] Tom O'Connor, "Russia Military's Future War Gear Gets a New Nuclear-Resistant Upgrade," *Newsweek*, October 10, 2017.

[86] Additional information on Cochlear implants is available at http://www.cochlear.com/wps/wcm/connect/intl/home.

[87] "Sydney Man has Opal Card Implanted into Hand to Make Catching Public Transport Easier," *ABC News*, June 27, 2017, available at http://www.abc.net.au/news/2017-06-27/sydney-bio-hacker-has-opal-travel-card-implanted-into-hand/8656174.

[88] James Brooks, "Cyborgs at Work: Swedish Employees Getting Implanted with Microchips," *Associated Press*, April 3, 2017, available at https://www.apnews.com/4fdcd5970f4f4871961b69eeff5a6585.

Early research has found that brain waves can be interpreted using a machine for simple functions such as thought-controlled movement. Applying this research offers the opportunity for more advanced augmentation. One example of this is the U.S. Defense Advanced Research Project Agency, which recently commenced examination of technologies that allow heads-up displays to be projected via the human visual cortex.[89] There is a history of humans accepting implantable technology to prolong life. It is not a big leap to accept that in future, if the technology is available, military personnel might receive implanted augmentation that enhances their physical and cognitive capabilities.

Enterprise and Battlefield Applications

Each of the above forms of augmentation are likely to see continued development over coming decades. At some stage there is also likely to be testing of implanted augmentation for the human brain. There are several reasons why this might be desirable: quicker and better recall of information, better analysis of options, replacement of lost capabilities (where soldiers may have suffered brain injuries); and potentially enhancements for mental resilience and the prevention of PTSD.

Efforts to this end are already underway. SpaceX and Tesla CEO Elon Musk is backing a brain-computer interface venture called *Neuralink*. This work seeks to design and build devices that can be implanted in the human brain with the intent of helping human beings merge with software and keep pace with advancements in AI. These could also potentially improve memory or allow for more direct interfacing with computing devices.[90]

By 2030 ground forces are highly unlikely to have achieved Ray Kurzweil's singularity, where AI and machines can outperform the human mind.[91] Robots and AI will proliferate, but they are likely to remain in the realm of "the science of war." Computers are not at the point—yet—where they might supplant what is currently understood as human creativity.[92] Therefore the "art of war" will remain the domain of people, at least in foreseeable future. But it is probable that technology will reach a point in the near future where AI, machines, and man-machine teaming will open a range

---

[89]   Kareem Ayoub and Kenneth Payne, "Strategy in the Age of Artificial Intelligence," *Journal of Strategic Studies* 39, no. 5–6, 2016, p. 814.

[90]   Rolfe Winkler, "Elon Musk Launches Neuralink to Connect Brains with Computers," *Wall Street Journal*, March 27, 2017.

[91]   The technological singularity (also, simply, the singularity) is the hypothesis that the invention of artificial super intelligence will trigger runaway technological growth, resulting in unfathomable changes to human civilization.

[92]   Margaret A. Boden, "Artificial Creativity," *MIT Technology Review*, October 20, 2015, available at https://www.technologyreview.com/s/542281/artificial-creativity/; and Will Knight, "Amazon Has Developed an AI Fashion Designer," *MIT Technology Review*, August 24, 2017, available at https://www.technologyreview.com/s/608668/amazon-has-developed-an-ai-fashion-designer/.

of new and exciting possibilities.[93] These will enrich society but profoundly challenge how military organizations think about the profession of arms.

FIGURE 2: SOLDIER AND LOAD CARRYING ROBOT

A Soldier of the 25th Infantry Division remote controls a Kobra 710 during the Pacific Manned Unmanned-Initiative (PACMAN-I) at Marine Corps Training Area Bellows, Hawaii, July 22, 2016. Manned-Unmanned Teaming is one of many new concepts that has been identified as part of the Army Warfighter Assessment 2017 (AWA 17). AWA is the U.S. Army Training and Doctrine Command's premier event to evaluate concepts and capabilities that address the Army's warfighting challenges and shape the future Army's force. Photo Credit: Kimberly Bratic, U.S. Army TARDEC.

---

[93]   U.S. Army, *The Operational Environment and the Changing Character of Warfare*, p. 9.

Chapter 3

The Challenges of Future Human-Machine Ground Forces

In the aftermath of the German U-boat campaign in the First World War, many in Europe and the United States argued that submarines were immoral and should be outlawed. The British Admiralty supported this view and, as Clay Blair has described, even offered to abolish their submarine force if other nations followed suit.[94] Although British proposals to ban submarines in 1922 and 1930 were defeated, restrictions on their use were imposed, which mandated that submarines could not attack a ship until such ships crews and passengers were placed in safety.

This reaction to the development of a new means of war is illustrative of the ethical and legal challenges that must be addressed in developing future human-machine teams. As a recent article in the *Harvard International Review* notes,

> Robotics and human enhancement also pose alarming prospects of ethical blowback. The depersonalization of warfare lowers the stakes of declaring war in the first place. Furthermore, biological and technological upgrades to the human body raise a host of concerns, such as risks to health, the ability to reintegrate into civil society, and the use of enhancements outside of warfare.[95]

---

[94]   Clay Blair, *Silent Victory: The U.S. Submarine War Against Japan* (Annapolis, MA: Naval Institute Press, 2001).

[95]   Veronica Ma, "The Ethics and Implications of Modern Warfare," *Harvard International Review*, January 16, 2017, available at http://hir.harvard.edu/article/?a=14494. See also Patrick Lin, George Bekey, and Keith Abney, *Autonomous Military Robotics: Risk, Ethics, and Design* (San Luis Obispo, CA: California Polytechnic State University, December 20, 2008); Robert Sparrow,

These challenges must be considered by ground forces concurrently with the development of the technical aspects of human-machine teaming. As a recent report by Lin and Bekey noted, "Given a significant lag time between ethics and technology, it is imperative to start considering the issues before novel technologies fully arrive on the scene and in the theatre of war."[96] The multiple challenges involved are the focus of this part of the study. These involve strategic, institutional and tactical issues, each posing serious ethical dilemmas.

The Strategic Challenges of Human-Machine Teaming

Easier Use of Force

The use of robots and advanced AI may lower the barrier for entry to war. Nations with this technology may find it easier to engage in war or adopt aggressive foreign policies that provoke other nations. If so, greater effort needs to be made to ensure that states comply with the principles of *jus ad bellum*.[97] This is a debate for a cross section of society—government, academia, military, and the broader community. In 2014, Steven Metz summed up the challenge for policymakers:

> It seems likely that a future president would find it easier to deploy a heavily or completely robotic unit and to keep it in the field for an extended time. This could help with deterrence and crisis containment. But by making it easier to use force, a robot centric military could also tempt a future president into conflicts and crises that the United States might otherwise avoid. . . . The Founding Fathers intentionally made it difficult for the United States to use force. Robots, like airpower, will erode this firebreak.[98]

The counter argument to this is that the unease of political decision-makers in using robotic systems may constrain their use. Further, recent initiatives in the United Nations to review the use of lethal autonomous weapons may see the rise of new international conventions and norms that govern their application in conflict.[99]

"Robots and Respect: Assessing the Case Against Autonomous Weapon Systems," *Ethics and International Affairs* 30, no. 1, March 10, 2016; Will Knight, "Military Robots: Armed, but How Dangerous?" *MIT Technology Review*, August 3, 2015; and Jean-Baptiste Jeangène Vilmer, "Terminator Ethics: Should We Ban Killer Robots?" *Ethics and International Affairs*, online exclusive, March 23, 2015.

[96] Lin, Mehlman, and Abney, *Enhanced Warfighters*, p. iii.

[97] I am grateful to Dr. Deane-Peter Baker, from the Australian Centre for the Study of Armed Conflict and Society for his input and comment on this issue.

[98] Steven Metz, "Strategic Insights: The Land Power Robot Revolution is Coming," *Strategic Studies Institute*, U.S. Army War College Press, December 10, 2014, available at http://ssi.armywarcollege.edu/index.cfm/articles/Landpower-Robot-Revolution/2014/12/10.

[99] The most recent series of meetings was held in Geneva in April 2018. See "2018 Group of Governmental Experts on Lethal Autonomous Weapons Systems (LAWS)," United Nations Office at Geneva, website, available at https://www.unog.ch/__80256ee600585943.nsf/(httpPages)/7c335e71dfcb29d1c1258243003e8724?OpenDocument&ExpandSection=7#_Section7.

Destabilizing Influences

Altman and Sauer have argued that the application of autonomous robots and AI by the military will have a negative impact on strategic stability. Using Cold War history, they suggest that the attractiveness of drone and AI technology to state and non-state actors will result in proliferation of lethal autonomous weapon systems and a new arms race. Given the potential incentives for pre-emptive operations using low-cost swarming drones, documented Cold War examples of computerized early warning errors, and the possibility of stealthy drones holding nuclear delivery systems at risk, they argue that the introduction of robotics and AI will result in a less stable security environment.[100]

Strategy Development

Future human-machine teaming may pose challenges to strategy development and implementation. As Hew Strachan has noted,

> It is patently absurd to deny that the impact of new technology can be strategically significant. . . . The steamship, the manned aircraft or the rocket, have triumphed over geography, changing the relationship between space and time, and thus have a geopolitical effect as well as a directly operational one.[101]

The introduction by the U.S. of the new technology of atomic weapons changed the strategic calculus of major powers in the wake of the Second World War. As Colin Gray notes, "There is general agreement among strategic theorists . . . that there was a phenomenon worth calling the 'nuclear revolution.' This revolution cast a shadow over all statecraft and strategy."[102] Similarly, robots, AI, and human augmentation applied in concert with new organizations and operational concepts may have an impact on military strategy.[103]

The application of AI as a strategic decision support tool may also address some of the human fragility and bias inherent in strategy development and implementation.[104] AI is not subject to physical issues such as fatigue and can be built to take account of other psychological dimensions

---

[100] Jürgen Altmann and Frank Sauer, "Autonomous Weapon Systems and Strategic Stability," *Survival: Global Politics and Strategy* 59, no. 5, September 18, 2017.

[101] Hew Strachan, *The Direction of War: Contemporary Strategy in Historical Perspective* (Cambridge, UK: Cambridge University Press, 2013), pp. 190–191.

[102] Colin S. Gray, *Modern Strategy* (Oxford, UK: Oxford University Press, 1999), pp. 203–204.

[103] Strachan, *The Direction of War*, pp. 190–192. In a recent article, Paul Scharre also proposes that autonomous robotics systems, or drones, pose a challenge for foreign policy. Paul Scharre, "The Coming Drone Wars: A Headache in the Making for American Foreign Policy," *The National Interest*, July 25, 2017, available at http://nationalinterest.org/feature/the-coming-drone-wars-headache-the-making-american-foreign-21662.

[104] The issue of AI and strategy making is examined in detail in Ayoub and Payne, "Strategy in the Age of Artificial Intelligence."

of strategy such as cognitive load, risk taking and aversion, and bias. It can assess large amounts of data, challenge long-held human assumptions, and recognize patterns missed by humans. However, AI is limited by programming and the data sets available to it. Further, AI may produce strategies that breach the values, ethics, or strategic objectives of its human users.[105] Regardless, it is apparent that AI will impact strategy and strategic decision-making. The degree to which it does must be decided by policymakers and senior military leaders.

Recent incidents of AI misbehavior have demonstrated the need for such scrutiny. Instances of algorithmic defamation have included Google search engine routines learning to make defamatory or bigoted associations about groups of people.[106] A 2016 study of the use of algorithms to support criminal sentencing in the United States found systemic racial bias in risk estimation.[107] A 2017 report from *AI Now* raised concerns with the use of invalidated or unreviewed algorithmic systems in social systems such as justice, welfare, and other government services.[108]

More infamous cases of algorithmic misbehavior are the 2010 "Flash Crash"[109] and the 2016 offensive public statements of Microsoft AI chatbot, Tay.[110] These indicate that we still have much to learn about the shortcomings of AI and machine learning. One writer for *The Verge* online technology magazine posed an important question in the wake of the Tay incident: "How are we going to teach AI using public data without incorporating the worst traits of humanity?"[111]

---

[105] Ibid., pp. 807–808.

[106] Nicholas Diakopoulos, "Algorithmic Defamation: The Case of the Shameless Autocomplete," *Tow Center for Digital Journalism*, August 6, 2013, available at http://towcenter.org/algorithmic-defamation-the-case-of-the-shameless-autocomplete/.

[107] This example is examined in detail in Osonde A. Osoba and William Welser IV, *An Intelligence in Our Image: The Risks of Bias and Errors in Artificial Intelligence* (Santa Monica, CA: RAND Corporation, 2017), pp. 13–15.

[108] Alex Campolo, Madelyn Sanfilippo, Meredith Whittaker, and Kate Crawford, *AI Now 2017 Report* (New York: AI Now Institute, New York University, 2017), available at https://assets.contentful.com/8wprhhvnpfc0/1A9c3ZTCZa2KEYM64Wsc2a/8636557c5fb14f2b74b2be64c3ce0c78/_AI_Now_Institute_2017_Report_.pdf.

[109] On May 6, 2010, U.S. share and futures indices dropped 10 percent in a matter of minutes, with some blue-chip shares briefly trading at a one cent, only to recover most of the lost ground before the end of the trading day. The trigger for the sudden decline was a large sell order in "e-mini" futures on the S&P 500 index by an unnamed mutual-fund group. "What Caused the Flash Crash?" *The Economist*, October 1, 2010; U.S. Commodity Futures Trading Commission (CFTC) and the U.S. Securities and Exchange Commission (SEC), *Findings Regarding the Market Events of May 6, 2010*, Report of the Staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues (Washington, DC: CFTC and SEC, September 30, 2010), available at https://www.sec.gov/news/studies/2010/marketevents-report.pdf.

[110] On March 23, 2016, Microsoft unveiled Tay—a Twitter bot described as an experiment in "conversational understanding." The more you chat with Tay, said Microsoft, the smarter it gets, learning to engage people through "casual and playful conversation." Soon after Tay launched, people started tweeting the bot with all sorts of misogynistic, racist, and other offensive remarks. Tay then started repeating these sentiments on its Twitter feed. Hannah Francis, "Microsoft's Teenage Chatbot Tay Turns into Racist, Abusive Troll," *Sydney Morning Herald*, March 25, 2016.

[111] James Vincent, "Twitter Taught Microsoft's AI Chatbot to Be a Racist Asshole in Less than a Day," *The Verge*, March 24, 2016, available at https://www.theverge.com/2016/3/24/11297050/tay-microsoft-chatbot-racist.

These misbehaving algorithms are the result of shortfalls in human specification and can lead to incorrect, inequitable, or dangerous outcomes. [112] These incidents also underscore the need for a greater understanding of AI's shortfalls by decision-makers and more rigorous testing prior to operational use. As Will Knight noted recently, "Knowing AI's reasoning is also going to be crucial if the technology is to become a common and useful part of our daily lives." [113] Even if this understanding is not resident in a majority of the military personnel, there will need to be a core of personnel who possess sufficient knowledge and technical ability to audit the output of AI and the various algorithms that will be used. [114]

Responsibility

Some contend that human beings may not always be responsible for the behavior of machines (technologies) because of artificial agents that have the capacity to learn as they operate. This is described by Mathias as a responsibility gap, and he notes,

> Presently there are machines in development or already in use which are able to decide on a course of action and to act without human intervention. The rules by which they act are not set during the production process, but can be changed during the operation of the machine, by the machine itself. [115]

However, as Johnson writes, "A responsibility gap will not arise merely from the technological complexity of artificial agents. . . . Whether or not there will ever be a responsibility gap depends on human choices not technological complexity." [116] Horowitz and Schafer have also written, "Weapons themselves do not comply with the laws of war. Weapons are used by people in ways that comply with, or violate, the laws of war." [117] Leaving humans in the loop and humans on the loop will be critical in both the design and early deployment of lethal systems in human-machine teaming.

It will be important for the issue of responsibility to decide who, or what, makes the decision for a robot to kill. Some situations may develop so quickly and require such rapid information processing that we would want to entrust our robots and systems to make critical decisions. If

---

[112] Misbehaving algorithms is the subject of a recent report from RAND. Osoba and Welser, *An Intelligence in Our Image*.

[113] Will Knight, "The Dark Secret at the Heart of AI," *MIT Technology Review*, April 11, 2017, available at https://www.technologyreview.com/s/604087/the-dark-secret-at-the-heart-of-ai/.

[114] Osoba and Welser, *An Intelligence in our Image*, p. 25.

[115] Andreas Matthias, "The Responsibility Gap: Ascribing Responsibility for the Actions of Learning Automata," *Ethics and Information Technology* 6, no.3, September 2004.

[116] Deborah G. Johnson, "Technology with No Human Responsibility," *Journal of Business Ethics* 127, no. 4, April 2015.

[117] Michael C. Horowitz and Paul Scharre, "The Morality of Robot War," *The New York Times*, May 26, 2015, available at https://www.nytimes.com/2015/05/27/opinion/the-morality-of-robotic-war.html.

human soldiers monitor the actions of each robot as they occur, it may limit the effectiveness for which the robot was designed in the first place.[118]

It might be argued that this Rubicon was crossed when *Predator* drones were armed in the early 2000s and used widely to dispatch terrorists and insurgents with their missile armament. Similarly, ISIS terrorists used ground and air unmanned vehicles to deliver lethal payloads in the Battle for Mosul in 2017. But ultimately the decision to kill humans by these machines was made by a human operator. At least in the case of the U.S. and UK, it was done in accordance with endorsed rules of engagement.[119] But military organizations must look beyond this and examine whether it is desirable to have robots able to kill humans based on automated processes and without a human in the decision cycle.

Civil-Military Relations

The relationship between military organizations, and the societies they serve, may be stressed if augmentation is applied to military personnel. It is likely that mechanical, and eventually cognitive, augmentation will be expensive and beyond the means of most people. As Yuval Harari has noted, this could see a differentiation in how society views augmented and non-augmented people. Harari notes,

> Splitting humankind into biological castes will destroy the foundations of liberal ideology. Liberalism can coexist with socioeconomic gaps. Indeed, since it favours liberty over equality, it takes such gaps for granted. However, liberalism still presupposes that all human beings have equal value and authority.[120]

In Western democracies, this poses profound questions about equality and the value of individuals within society. Ground forces must examine this and make a compelling case to their governments and wider societies if they are to implement human augmentation.

---

[118] Lin, Bekey, and Abney, *Autonomous Military Robotics*, pp. 74–75.

[119] For more on the debate on the use of armed unmanned aircraft and the laws of armed conflict, see Milena Sterio, "The United States' Use of Drones in the War on Terror: The (Il)legality of Targeted Killings under International Law," *Case Western Reserve Journal of International Law* 45, no. 1, 2012; Kenneth Anderson, Daniel Reisner, and Matthew Waxman, "Adapting the Law of Armed Conflict to Autonomous Weapon Systems," *International Law Studies* 90, no. 1, 2014; and Lynn E. Davis, Michael McNerney, and Michael D. Greenberg, *Clarifying the Rules for Targeted Killing: An Analytical Framework for Policies Involving Long-Range Armed Drones* (Santa Monica, CA: RAND Corporation, 2016).

[120] The liberal solution for social inequality is to ensure equal value is given to different human experiences instead of trying to create the same experiences for everyone. However, will this still work if human augmentation creates real biological gaps? Harari, *Homo Deus*, pp. 403–404.

Challenges for Ground Forces as Institutions

Institutional Culture

Institutional culture will pose significant barriers to any widespread deployment of robotics and AI. This will particularly be the case where these systems displace humans. Military organizations for most of history have seen themselves as human institutions. This has reinforced people-centric team cultures. Additionally, different military occupational specialties have developed unique sub-cultures within the larger force. These cultures and sub-cultures are powerful elements in developing cohesion and *esprit de corps*. But they can also be barriers to change and the adoption of new ideas, techniques, and technologies.[121]

This can be magnified by the bureaucratic inertia that is resident in every large organization. Therefore, new incentive systems and career structures will be required to enable the institutional changes that will be driven through human-machine teaming. Changing organizational culture will need to be a focus for leaders at all levels in the development of more integrated human-machine teams.

Combat Concepts

Employing human-machine teams will demand examination of how the ground force fights, both in combined arms and as part of a joint force. This idea of how a future land force might fight is as important, and potentially more so, than the new technology employed by its people. As Trevor Dupuy wrote, "The importance of new or imaginative ideas in military affairs, as opposed to simply new things, can best be gauged by the fact that new ideas have often permitted inferior military forces to overcome forces that were larger and better equipped."[122]

Currently, all forms of unmanned systems are integrated in human-centric concepts of operations. This limits the potential of human-machine teams by implicitly designing operations around the limits in human performance.[123] Future warfighting concepts for a human-machine ground force must move beyond this construct and be developed well in advance of major investment decisions.

---

[121] The issue of resistance to change in military organization is examined in a range of books and other publications. Among the best are: Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca, NY: Cornell University Press, 1991); James S. Corum, *The Roots of Blitzkreig: Hans von Seeckt and German Military Reform (*Lawrence, KS: University Press of Kansas, 1992); Williamson Murray and Allan R. Millet, eds., *Military Innovation in the Interwar Period*, revised edition (New York: Cambridge University Press, 1998); MacGregor Knox and Williamson Murray, eds., *The Dynamics of Military Revolution 1300–2050* (New York: Cambridge University Press, 2001); David E. Johnson, *Fast Tanks and Heavy Bombers: Innovation in the U.S. Army 1917–1945* (Ithaca, NY: Cornell University Press, 2003); Michael E. O'Hanlon, *Technological Change and the Future of Warfare* (Washington, DC: The Brookings Institution, 2000); Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, NJ: Princeton University Press, 2010); and Dima Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel* (Stanford, CA: Stanford University Press, 2010).

[122] Dupuy, *The Evolution of Weapons and Warfare*, p. 316.

[123] Ilachinski, *AI, Robots, and Swarms*, p. xvi.

These issues, which incorporate the technical, the ethical, and the organizational, must be addressed if effective human-machine teams are to be designed and employed during operations.

Network and Information Security

The design and implementation of a secure network to connect humans and machines in this integrated force will be an important foundation. A secure network must be designed at the institutional level to connect tactical organizations (for land, joint, and coalition forces). This network must also link those deployed in the battlespace with strategic reach-back capabilities. It is a challenge for network architecture, and solutions are needed where the information that flows across a human-machine network is secure and assured.

The persistent threat to friendly networks is well known and described in a range of official and academic publications.[124] Any design for integrated ground force human-machine teams must be founded on resilient, robust, and trusted networks that connect humans and machines within, and between, teams. Defense research organizations such as the U.S. Army Research Laboratory,[125] the United Kingdom's Defense Science and Technology Laboratory,[126] and Australia's Defense Science and Technology Group[127] all have active programs seeking to provide more resilient and reliable networks for future military operations.

This challenge is particularly acute when humans must trust their lives to decision support by algorithms within networks. Their security must be assured. In hardening the networks that enable human-machine teaming, security must not compromise the speed—or tempo—of operations. To achieve secure networks, ground forces must ensure they don't give away the competitive advantage that is desired through the application of AI and robotics in networked human-machine teams.

Personnel, Education, and Training

A new approach to education and training will be required in an integrated human-machine force. Throughout history, military training has focused on teaching humans to achieve outcomes as individuals and teams. In a human-machine ground force, this foundational approach to training is challenged. Similarly, education for military leaders currently seeks to achieve their intellectual

---

[124]   Key national strategies that address this issue include the American *The Department of Defense Cyber Strategy* (April 2015); the Australian *Australia's Cyber Security Strategy, 2016* (2016); and the UK's *National Cyber Security Strategy 2016-2021* (2016).

[125]   The U.S. Army is progressing a range of inter-connected networking security initiatives under their Information Sciences Campaign Plan.

[126]   Among the UK programs is a Contested Electromagnetic Program; see more at https://www.gov.uk/guidance/contested-electromagnetic-environment-programme.

[127]   The Australian research program in this area is conducted under the Defense Science and Technology Group's Information and Communications program; see https://www.dst.defence.gov.au/research-area/information-and-communications.

development in the art and science of war. If learning machines are added to this environment, both institutional and individual professional military education must adapt.

Part of any new training and education approach will be developing the understanding of common goals in human-machine teams. Humans and autonomous machines will need common goals and share awareness if they are to work together effectively. Many commercial aircraft accidents associated with automation occurred when the flight crew had one goal (for example, staying on the glide slope during an approach) and the flight management computer had another (such as executing a go-around).[128] Called "automation surprises," this is where human operators have failed to observe or intervene in machine behavior, resulting in undesirable outcomes. Deploying future autonomous systems will demand good human training, as well as increasing each machine's awareness of what the human or humans are trying to achieve.

Career development and management of military personnel will also need to be adapted to the new human-machine force. As robots replace humans in many "dirty, dull and dangerous" functions, it is possible that many lower ranking soldiers may be displaced. This will necessitate a change to the traditional career pyramids, where the mass of an Army is found in the lowest ranks.

Costs

The financial cost of robotic systems, AI, and augmenting humans will add to existing challenges of institutional budgeting. The amount of investment likely to achieve a deeper level of human-machine integration—in research, experimentation, and deploying systems—is likely to run into tens of billions of dollars across Western ground forces. For example, the United States Defense Advanced Research Projects Agency in Fiscal Year 2018 alone plans to spend over U.S. $735 million in two of its offices that undertake research into robotics and algorithms.[129] Ground forces will need to decide on an appropriate level of investment in such an approach, as opposed to the procurement of more traditional human-operated equipment over the next two decades.

Procurement Bureaucracy

Related to this is the challenge of reforming Defense procurement bureaucracies to support a shift to a more integrated human-machine design. Procurement policy and processes in Western nations are generally designed to minimize procurement risk for governments and government departments and ensure that taxpayer resources are maximized with minimal waste. Such long

---

[128]   One useful study of multiple aircraft accidents that covers these issues with automation is Christine Negroni, *The Crash Detectives: Investigating the World's Most Mysterious Air Disasters* (New York: Penguin Books, 2016).

[129]   The DARPA Tactical Technology Office funds research into robotics—among other areas—and has an FY 2018 allocation of US$343 million. The Information Innovation Office funds research into algorithms and cyber issues and has an FY2018 budget of US$392 million. See the DARPA Budget at https://www.darpa.mil/about-us/budget.

procurement processes are unlikely to be suitable for an environment where AI developments and their applications are moving rapidly.

There is evidence that the world is now in the midst of a 4th Industrial Revolution.[130] However, the majority of Western military organizations are representative of 2nd and 3rd Industrial Revolution[131] structures and processes. Unless the decision-making approaches of these military organizations can be reformed and exploit the pace of technological change, they will face a growing "modernization gap,"[132] as described recently by retired Major General Robert Scales.[133]

Confronting Tactical Level Challenges

Cognitive Load

A key tactical challenge in the future teaming of humans and robots is that there may be an increased cognitive load on personnel. For example, it's possible an infantry soldier might be responsible for several air and ground unmanned vehicles, while also having to operate in a human team. Under normal circumstances, this would be demanding. In combat, it would place a severe cognitive load on an individual. Recruiting, training, education, assessment, and development of intellectual capacity and resilience will need to be adapted to address this issue.

Informed Consent

Consent by soldiers to the risks of working with robots and AI will be an issue that must be addressed. In October 2007, a semi-autonomous cannon deployed by the South African army malfunctioned, killing nine soldiers and wounding 14 others.[134] This is both a legal and an ethical quandary; should soldiers be informed that unusual or new risks exist, such as working with potentially defective robots?[135]

---

[130] A key proponent is Professor Klaus Schwab, but his themes have been applied more broadly to represent the changes in industry and society being driven by a convergence of technological breakthroughs in areas such as nanotechnology, quantum theory, biotechnology, autonomy, robotics, and artificial intelligence. For more see, Klaus Schwab, *The Fourth Industrial Revolution* (New York: Crown Business, January 2017).

[131] The 2nd Industrial Revolution saw the arrival of telephones, electric lights, and the internal combustion engine, and it ended in 1914. The 3rd Industrial Revolution heralded the digital age and saw the shift from analog to digital technologies, commencing in the 1980s with new technologies such as personal computers and the wide availability of the internet.

[132] Author's term.

[133] Scales wrote that "the art of predicting the course of war is made far more difficult by a quickening of the rate of change among those variables most likely to influence conflict such as technology, domestic politics, and international events. While the pace of influencing events is accelerating the capacity of militaries to build weapons and structures to accommodate change is slowing. Thus soldiers today must cast farther and farther out to stay ahead." Robert Scales, "Forecasting the Future of Warfare," *War on the Rocks*, April 9, 2018, available at https://warontherocks.com/2018/04/forecasting-the-future-of-warfare/.

[134] Noah Shachtman, "Robot Cannon Kills 9, Wounds 14," *Wired Magazine*, October 18, 2007, available at https://www.wired.com/2007/10/robot-cannon-ki/.

[135] Lin, Bekey, and Abney, *Autonomous Military Robotics*, p. 74.

Human Dignity

Philosophers such as Peter Asaro and Robert Sparrow, as well as non-government organizations and the Vatican, have argued that delegating the decision to target and open fire to a machine violates human dignity. At its core, this is a proposition that people have the "right not to be killed by a machine."[136] Technologists such as Stephen Hawking[137] and Elon Musk[138] have also spoken out against AI. Others, accepting that autonomous systems and AI are likely to play a large role in war and society in the future, have proposed concurrent efforts to develop technology and examine the ethics of these systems. As Amir Husain notes, "If autonomous systems are to be a pillar of future supremacy, then now is the right time to present a framework within which autonomy can be enabled in an effective and technically viable, yet legal and moral, manner."[139]

Trust

Perhaps the most important challenge is establishing trust. The degree to which military leaders should trust advanced analytics and artificial intelligence to make decisions about its people, and potentially make decisions about saving and taking lives, must be established. The level of trust people will place on objects implanted in their bodies to improve performance is also to be established. Finally, for augmented humans, it is yet to be proven whether they will be trusted in teams composed of augmented and non-augmented humans.

The current approach of many ground forces in employing mission command and decentralized command approaches offers some insights into how these questions might be at least partially answered. Mission command—the practice of assigning a subordinate commander a mission without specifying how the mission is to be achieved[140]—has established the foundational relationships between commanders and subordinates that might be adapted for trusted relationships with robots and AI. But it does not fully address the issues that must be examined and resolved in building a hybrid human-machine ground force.

---

[136] Vilmer, *Terminator Ethics*.

[137] Dom Galeon and Kristin Houser, "Hawking: Creating AI Could Be the Biggest Event in the History of Our Civilization," *Futurism*, October 20, 2016, available at https://futurism.com/hawking-creating-ai-could-be-the-biggest-event-in-the-history-of-our-civilization/.

[138] Maureen Dowd, "Elon Musk's Billion Dollar Crusade to Stop the AI Apocalypse," *Vanity Fair*, March 26, 2017, available at https://www.vanityfair.com/news/2017/03/elon-musk-billion-dollar-crusade-to-stop-ai-space-x.

[139] Amir Husain, "AI on the Battlefield: A Framework for Ethical Autonomy," *Forbes*, November 28, 2016, available at https://www.forbes.com/sites/forbestechcouncil/2016/11/28/ai-on-the-battlefield-a-framework-for-ethical-autonomy/#6dce16875cf2.

[140] Australian Army, *The Fundamentals of Land Power* (Canberra: Australian Army Headquarters, 2017), p. 45.

Mankind has wrestled with these types of challenges before. For centuries, the application of new technologies in war has generated debate during, before, and after conflict. In 1139, Pope Innocent II led the Second Lateran Council in banning the use of crossbows in war. At the time the crossbow represented very advanced technology that required minimal training and little strength and possessed unparalleled lethality. A hastily-trained peasant could use the weapon, challenging the existing power structure in war. The Roman Catholic Church viewed the new weapon as a gross transformation of the nature of war.[141] This reaction to a new means of war illustrates the type of concerns that military organizations must address in adopting plans for human-machine integration. Ground forces must possess realistic strategies that address these challenges if they are to successfully exploit the future of human-machine teaming.

---

[141] Ma, *The Ethics and Implications of Modern Warfare*.

Chapter 4

Building a Competitive Advantage: A Strategy for Future Ground Forces

Carl Builder once wrote, "An Army requires a theory of an Army. There must exist something in addition to its soldiers and tanks and guns—a concept, a strategy, a notion of who it is and what it wants to be, and what it is about and what it wants to be about."[142] In embracing a future vision of human-machine teaming, ground forces' future ideas of themselves will change. To fully exploit the potential of human-machine teaming, ground forces will require strategies to describe desired capability outcomes and priorities for investment. Concurrently, they must undertake doctrinal, conceptual, and culture adaptation. To that end, this final part of the study offers a strategy for ground forces to develop human-machine teams over the short and medium terms.[143]

Any strategy that is founded solely on the technology of human-machine integration is likely to fail. Multiple authors have examined innovation and sources of success over centuries of military history. A key finding, by authors such as Williamson Murray, Trevor Dupuy, and Stephen Peter Rosen, is that technology alone is unlikely to provide a sustained competitive advantage. But when

---

[142] Carl Builder, *The Masks of War: American Military Styles in Strategy and Analysis*, a RAND Corporation Research Study (Baltimore, MD: Johns Hopkins University Press, 1989).

[143] While the Australian Army and the ADF lack such an approach, institutions such as the U.S. Department of Defense and the U.S. Army have already released comprehensive strategies for their development and employment of autonomous systems and AI in future human-machine teams. See U.S. Army, *Robotic and Autonomous Systems Strategy*.

new technology is combined with new operating concepts and new organizational models, innovation is more likely to provide sustained advantage.

This was also a finding of the Pentagon's Office of Net Assessment in its examination of the impact of new technology in the late 1980s and early 1990s. Then Director of Net Assessment, Andrew W. Marshall, wrote,

> A large part of pre-eminence . . . will reside in superior ideas with respect to concepts of operation and in organizational innovation. Indeed, being ahead in concepts of operation and in organizational arrangements may be far more enduring than any advantages in technology or weapons systems employing them. [144]

A strategy for building human-machine teams must achieve a convergence of technology, operating concepts, and new organizations.

The best way to begin a strategy is to describe the ends of that strategy. The U.S. Army has recently described its ends in the employment of robotic and autonomous systems: "Army formations use RAS to increase combat effectiveness and to maintain overmatch in combined arms operations against capable enemies."[145] This is a useful starting point, but a broader notion of systemic employment of robotic systems, AI, and augmented humans is required. Therefore, for ground forces, an appropriate statement of the ends might be:

Ground forces employ robotic systems, AI, and augmented humans in integrated human-machine teams in preparing the land force at home and in combat to generate operational and strategic leverage, balancing operational and enterprise effectiveness, affordability, and institutional values.

Specific targets are also required. Initial targets would be the subject of experiments. Experiments in human-robot teaming could provide an initial core around which all subsequent human-machine teaming programs are built. Initial experiments in areas such as ISR battle, breach and break action, and close combat would include modest human-robot integration activities. Lessons from these experiments would provide the foundation for follow-on human-machine teaming activities. Subsequent experiments could expand in scope and complexity for human-robot teaming and then gradually include human-AI integration and augmented humans.

---

[144] Andrew W. Marshall, "Some Thoughts on Military Revolutions—Second Version," Memorandum for the Record, Office of the Secretary of Defense, Office of Net Assessment, August 23, 1993, p. 3.

[145] U.S. Army, *Robotic and Autonomous Systems Strategy*, pp. 11–12.

The Next Five Years

In the short term, research, experimentation, and planning will be critical. This will inform longer-term goals and the prioritization of resources. Over this period, ground force designers and strategic planners should consider three key lines of effort; *monitor, design,* and *experiment.*

Monitor: Ground forces should possess programs that are focused on monitoring developments in robotics, AI, big data analytics, and human augmentation. This will provide institutional understanding of where best practice and the most effective approaches are being implemented. It will keep ground force designers informed of potential capability acquisitions and it will encourage an appreciation of what possible enemies might be doing in this field. This monitor function should be a collaboration among Western ground forces, potentially with the U.S. Army as the lead agency.

Design: Ground force modernization staff must also commence designing the next generation human-machine teams.[146] This can be informed by teaming experiments, and collaboration with academia, industry, and allies. It must also be informed by employing agreed-upon long-term goals that stretch the imagination and push ground forces into new and innovative designs. Ground force designers should not be afraid to produce and discard many different models in this process. These designs must include the connective tissue of team—secure and assured networks.

This design phase must include a discourse on the various ethical issues involved. The military must not be caught wrong-footed by some of the issues that are now facing technology companies such as Facebook, Google, and Twitter. Established as small startup companies, they evolved quickly with growing user bases. But, these companies are now facing questions from governments in the United States and Europe concerning their influence on society. One co-founder of Twitter has noted that "there wasn't time to think through the repercussions of everything we did" in the early days of the company.[147] Given the lethality of many of the systems involved, designers of human-machine teaming for ground forces cannot afford to make similar mistakes.

Another element of this design effort must be a redesign of education and training models. Training people to develop individual mastery and to be proficient within teams at different scales is the current focus of the Army training model. This model must change when large numbers of autonomous and semi-autonomous machines are introduced at multiple levels across the combat

---

[146] One interesting recent design for a future land combat force—albeit at unit level—is contained in Jeff Becker, "How Lethal, Mobile, Protected and Aware?" *Small Wars Journal,* July 24, 2017, available at http://smallwarsjournal.com/jrnl/art/how-lethal-mobile-protected-and-aware.

[147] David Streitfeld, "Changing the World, but Not Quite the Way They Had Imagined," *The New York Times*, October 13, 2017, pp. A1, A11.

force and wider enterprise. It will also drive a wider adoption of simulation to develop effective human-machine teams.

At the individual and small unit levels, more integrated human-machine teaming will increase cognitive loads on almost every soldier. For leaders, building best practices in employing AI will result in changes to officer and junior leader development as well as institutional professional military education programs. Where human augmentation is implemented, developing trust between augmented and non-augmented team members will be an important outcome of training. Overall, this will drive change in attracting and recruiting new personnel, educational programs to enhance intellectual resilience, and the broader approach to education and training.

The design of this new integrated human-machine force will also drive changes in military personnel management. Current military personnel models are constructed upon the all-volunteer professionalized military model which emerged in the later stages of the Cold War. Automation and AI is changing workforce patterns in civil industry. Military personnel experts will also have to change their approach to personnel modelling and career development. Military personnel in this new human-machine ground force will be involved in very different forms of work. Some old specialties are likely to disappear, and new ones will be formed. Military personnel experts should anticipate these changes and begin their strategic planning for this now.

Another aspect of design must be planning for organizational and cultural change that will accompany the adoption of large numbers of robots, AI, and augmented humans. This should blend new technology, new operating concepts, and innovative organizational design. There are many guides to successful implementation of organizational change. For military innovation, Murray and Millet,[148] Rosen,[149] and O'Hanlon[150] all offer lessons in adopting new ideas and technologies. However, one of the most relevant guides to organizational change is a short 1983 article from *Military Review* entitled "To Change an Army." In this article, retired General Don Starry examined how the U.S. Army reformed itself after Vietnam. It offers several mechanisms that would—in a military organization—provide the best chance for organizations to adapt successfully.[151] Three are relevant in the design for organizational change:

---

[148] Their three-part series, *Military Effectiveness* (1988), and the later *Military Innovation in the Interwar Period* are very fine examinations of military innovation and organizational change. Allan R. Millett and Williamson Murray, eds., *Military Effectiveness*, volume 1, *The First World War* (London: Unwin Hyman, 1988); Allan R. Millett and Williamson Murray, eds., *Military Effectiveness*, volume 2, *The Interwar Period* (London: Unwin Hyman, 1988); Allan R. Millett and Williamson Murray, eds., *Military Effectiveness*, volume 3, *The Second World War* (London: Unwin Hyman, 1988); Murray and Millett, eds., *Military Innovation in the Interwar Period*.

[149] Rosen, *Winning the Next War*.

[150] O'Hanlon, *Technological Change and the Future of Warfare*.

[151] Donn A. Starry, "To Change an Army," *Military Review* 63, no. 3, March 1983.

1. Institutional mechanisms must be established that are able to identify the need for change, draw up parameters for change, and describe clearly what must be done where change is required.

2. Someone at or near the top of the institution must be willing to hear out arguments for change, agree to the requirement for change, embrace the new operational concepts, and become a champion for that change.

3. There must senior advocacy for change. This advocacy must build a consensus that will give the new ideas, and the need to adopt them, a wider audience of converts and believers.[152] These will be vital elements of the design for change—and for a ground forces' overall design process to build a more integrated human-machine land force.

Experiment: Finally, ground forces must experiment. There are sufficient robotic systems, advanced analytic capabilities, early generation augmentable capability, and manned-unmanned teaming concepts to commence experiments now.[153] These experiments should initially entail the battlefield use of robots as a core function around which AI and augmentation could subsequently be applied.

Where fully realized systems are not yet available, sophisticated simulation programs can be used to underpin experimentation. Modeling will also be required on the fleet management of many types of robots. As most robots will be employed in teams with other robots, the fleet management of robots may take on many of the aspects of the extant personnel management processes, combined with best practice logistic fleet management.

These experiments might be restricted to the ground force of a single nation, or they may be conducted with allies or with industry and academia. For example, ground forces might partner with indigenous universities and other research centers. Western ground forces might also undertake collaborative experimentation with the U.S. Army as it implements its 2017 *Robotics and Autonomous Systems* strategy to develop the capacities to reduce the number of humans in harm's way, increase the speed of decision-making in time-critical operations, and to perform mission sets that are not possible for humans to perform.[154] Working with academia and with the U.S. Army, Western ground forces could establish small teams to generate prototype robotic, AI, and augmentation solutions. Regardless of the methods selected for experimentation, ground

---

[152] Starry, "To Change an Army," p. 23.

[153] The U.S. Army has already undertaken an extensive range of experiments with human-machine teams. These include the functions of fires, reconnaissance, and logistics. It expects these experiments to continue for at least the next decade. Jen Judson, "U.S. Army Tackles Teaming Robots and Ground Forces on Battlefield," *Defense News*, August 25, 2017, available at http://www.defensenews.com/land/2017/08/25/us-army-tackles-teaming-robots-and-ground-forces-on-battlefield/.

[154] U.S. Army, *Robotic and Autonomous Systems Strategy*, p. 2.

forces are facing a profound change in how they design future structures. These experiments will allow them to learn, to fail, and to inform successive ground force designs.

The Midterm to 2030

Looking beyond the initial monitor, design, and experiment phase, ground forces will need to focus on *deciding, investing,* and *shaping*.

Decide: Early in the next decade, ground forces will need to make substantial decisions about their future. These decisions will include the shape, size, and look of the land force. Other decisions will include the balance of combat and non-combat work forces, and how training and education systems must be adapted to this entirely new human-robot workforce construct. Ground forces will also need to decide how comfortable they are with employing lethal autonomous systems and AI systems making decisions about planning, intelligence, and logistics. These decisions must be informed by discourse throughout military institutions as well as wider national communities. Preferably, this discourse should be occurring now to allow time to work through the ethical and other challenges involved in human-machine teaming.

Invest: Based on these decisions, ground forces will need to invest. Different nations will assess their requirements for human-machine teaming differently. There is unlikely to be a single approach to the level of investment applied by various Western ground forces. But, development of human-machine teams may demand that ground forces also invest in the capability for developing robots and artificial intelligence that is resident in their national universities, and larger corporate research departments. A "sovereign capability" approach for each nation could provide a more secure approach to developing key technologies—and a foundation for sharing different approaches.

Investment will also be required in the education and training of people that will underpin this more integrated human-machine teaming. The training of ground forces must be reoriented to balance the development of people in individual mastery with building human-machine teams. Similarly, investment in an improved professional military education will be required. This could be focused on enhancing individual capacity to handle increased cognitive loads and building highly effective processes for incorporating AI into planning and decision support at multiple levels of command. Institutional professional military education programs will need to continue emphasis on mastery of the intellectual aspects of the profession of arms. However, courses that deliver learning outcomes in planning, tactics, and the execution of operations must incorporate the employment of AI.

Shape: Professional military education must be adapted to include more technically-oriented subjects to build a stronger foundation of technical and digital literacy in all leaders. In a more integrated human-machine institution, professional mastery will comprise of deep understanding

of the human nature of war complemented with a broad understanding of a wide variety of technical elements of the profession.

There will be many who will be skeptical or even afraid of some of these human-machine systems. The lethal, autonomous systems are likely to give pause to political and community leaders. Ground forces must apply their strategic communications capability to inform these external actors about its plans and force structure aspirations.

Conclusion

In the early twenty-first century, the train of progress is again pulling out of the station—and this will probably be the last train ever to leave the station called Homo Sapiens. Those who miss this train will never get a second chance. In order to get a seat on it you need to understand twenty-first century technology, and in particular the powers of biotechnology and computer algorithms. . . . Those left behind will face extinction.

Yuval Harari, 2015[155]

Society has yet to reach the technological mastery of the robots described by Isaac Asimov and Phillip K. Dick.[156] Nor has mankind achieved the levels of artificial intelligence shown in films such as Stanley Kubrick's masterpiece *2001 A Space Odyssey*[157] or the cognitive augmentation described by John Scalzi in *Old Man's War*.[158] But a review of historical technology development shows that exponential patterns of development extend beyond Moore's law. Wireless capacity doubles every nine months. Internet bandwidth backbone is doubling roughly every twelve months. During the 20th century, the range and effectiveness of artillery increased by a factor of twenty and antitank fire by a factor of sixty.[159] There is sufficient evidence to suggest robotics, AI, and augmentation will chart a similar path in capability growth.

---

[155] Harari, *Homo Deus*, p. 319.

[156] Dick's 1968 classic, *Do Androids Dream of Electric Sheep*, follows the exploits of a bounty hunter chasing sophisticated androids that are nearly indistinguishable from humans. Philip K. Dick, *Do Androids Dream of Electric Sheep* (New York: Doubleday Books, 1968).

[157] Regarded as one of the most influential films ever made, Kubrick's 1968 film was based on the 1968 book of the same name by Arthur C. Clarke.

[158] John Scalzi's *Old Man's War* series features elderly residents of earth being transformed into genetically engineered soldiers implanted with BrainPal computers in their heads, which provide cognitive enhancement but also coordinate all non-organic elements of their bodies. John Scalzi, *Old Man's War* (New York: Tor Books, 2005).

[159] Singer, *Wired for War*, p. 99.

Human-machine teaming has the potential to make soldiers much more effective—on the battlefield and while training at home. The capabilities of new robots and AI, and the potential of augmentation, also offer a potential revolutionary shift in how ground forces plan, train, and fight. It requires ground forces to be reoriented around the opportunities of the human-machine revolution. But it is an area replete with complex issues. Technological aspects cannot—and must not—be separated from ethical, moral, and legal issues.

At its core, human-machine teaming is not just about better technology for ground forces. It is about how clever organizations might leverage advancing technology and combine it with new ideas on warfighting and new institutional and warfighting structures. This has been the basis of all successful historical step-changes in military capability.[160] It will demand a sustained institutional and strategic focus on experimentation, research, and development. It will need significant investment to build what may become a decisive military edge for allied ground forces by the middle of the 21st century.

The broad potential applicability of these systems means that ground forces will need to adopt an enterprise approach to the employment of human-machine teams. Human-robot teams can be used in training institutions, potentially freeing up personnel to be re-deployed into other functions. Advanced computing and analytical capacity may be very useful in human-AI teams for strategic decision-making, capability development, resource allocation, and talent management.

Beyond investing in the force, Western armies may choose to support the development of sovereign capabilities for developing robots and artificial intelligence. With the potential scale for procurement, and inherent security risks of networked lethal robotic systems, allied nations should aspire to sustain national robot, AI, and augmentation research, design, and manufacture capabilities to support military and other applications.

Notwithstanding the attractiveness of such an approach, there are considerable challenges in developing a more integrated human-machine force. The strategic challenges will affect not just the military but will also have an impact on policymakers and political leaders. At the institutional level, resistance to change will challenge senior leaders. At the tactical level, ensuring that soldiers are not confronted by cognitive overload and have opportunities to build trust in their robot and AI partners will be essential.

This study offers a roadmap for more capable future ground forces. Ground forces should exploit the utility of human-machine teams to generate advantage on the battlefield and improve the effectiveness and efficiency of military activities at home. As one recent author noted, "Countries who fail to adequately develop autonomous warfighting systems are more likely to be the victims

---

160 Andrew F. Krepinevich and Barry D. Watts, *The Last Warrior: Andrew Marshall and the Shaping of Modern American Defense Strategy* (New York: Basic Books, 2015), p. 200.

of them. The autonomous arms race has begun. Liberal societies can either participate or risk the loss of a military advantage that might one day endanger their sovereignty."[161] This is a capability that future ground forces must possess. They have the opportunity now, with prudent strategic planning and investment, to build a winning capability advantage.

---

[161] Jules Hurst, "Intervention and the Looming Choices of Autonomous Warfighting," *War on the Rocks*, August 25, 2016, available at https://warontherocks.com/2016/08/intervention-and-the-looming-choices-of-autonomous-warfighting/.

The Near Future: D+10 Days

The operations officer, Major Kinsey, handed a mug of coffee to his Sergeant Major.

The Sergeant Major turned and spoke softly. "How's the skipper doing?"

Kinsey pondered this for a minute. "The micro-drone that caught his scent nearly killed him. . . . He still ended up with a decent head wound. The doctor bots are plugging him in. He should be up and about in a few weeks." The new cognitive implants installed by field hospital surgical robots would replace most of the function lost by the shrapnel wounds to their commander's brain. With some intensive physical and cognitive therapy, he'd be walking again within a month.

The two men both stared out across the now quietened city. The operation had gone generally according to plan several days before. They had lost more unmanned ground vehicles than Merlin had forecast, but they could be replaced relatively quickly from their field additive fabrication facility. The human toll, while heartbreaking, had been much lighter than they had anticipated.

They had employed the old Kilcullen ideas about the metabolism of the city and key node control. Now their battlegroup and the hundreds of unmanned ground vehicles and aerial drones accompanying them were, according to Merlin, deployed in an optimal operating disposition. There were four more days before the relief-in-place with the follow-on forces would arrive.

"Well then sir, I need to do another circulation before hitting the sack. I will see you on the VR for orders in the morning."

The battlegroup operations officer watched the Sergeant Major move away, quiet as a wraith. Major Kinsey turned and walked toward his low signature command vehicle. He had ten

minutes before the virtual planning group with the Brigade operations team for deploying the new stealth unmanned ground vehicle motherships on their next mission in two weeks.

Acronyms

AI	artificial intelligence
DARPA	Defense Advanced Research Projects Agency
CEO	Chief Executive Officer
U.S.	United States
GPS	Global Positioning System
UAV	unmanned aerial vehicle
ISIS	Islamic State of Iraq and Syria
ISR	intelligence, surveillance, and reconnaissance
UK	United Kingdom
CIWS	Close-In Weapons System
OODA	Observe, Orient, Decide, Act
LAN	local area network
HULC	Human Universal Load Carrier
XOS	Raytheon's Exoskeleton
BLEEX	Berkeley Lower Extremity Exoskeleton
USSOCOM	United States Special Operations Command
TALOS	Tactical Assault Light Operator Suit
PTSD	Post-Traumatic Stress Disorder
PACMAN-I	Pacific Manned Unmanned-Initiative
AWA	Army Warfighter Assessment
RAS	robotic and autonomous systems
ADF	Australian Defense Force
VR	virtual reality

CSBA

Center for Strategic and Budgetary Assessments

1667 K Street, NW, Suite 900
Washington, DC 20006
Tel. 202-331-7990 • Fax 202-331-8019
www.csbaonline.org