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Industry Study

Industry Report
Robotics and Autonomous Systems

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Robotics and Autonomous Systems 2018

ABSTRACT: Technological superiority is a primary source of national power and no other industry is poised to influence that power as is robotics and autonomous systems. Robotics and autonomous systems' "killer app" is artificial intelligence (AI), and it will be disruptive to the global economic and security paradigm. America is in a strong strategic position with respect to AI, but its development has been uncoordinated: the technology has been evolving in isolated pockets; the population appears somewhat reticent to adopt it; the science is moving faster than policy can regulate it; and industry's interests are diverging from those of the nation. AI needs to be instituted as a system consisting of the technology, society, governance, and industry. Government can do so by lending coherence and integration to the national effort to institute AI, engendering trust in AI, and incentivizing industry to return to a focus on innovation, quality, and value. The mechanism to attain this is via a National Artificial Intelligence Strategy.

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Field Studies – Domestic:

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Carnegie Mellon University's National Robotics Engineering Center, Pittsburgh, PA
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CyPhy Works, Danvers, MA
Defense Innovation Unit Experimental, Mountain View, CA
Dunkworks, Woods Hole, MA
Endeavor Robotics, Chelmsford, MA
Global Resilience Institute, Boston, MA
HEBI Robotics, Pittsburgh, PA
Hurdler Motors Incorporated, Boston, MA
IAM Robotics, Sewickley, PA
IBM Almaden Laboratory, San Jose, CA
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Lawrence Livermore National Laboratory, Livermore, CA
Lockheed Martin, Advanced Technology Laboratories, Crystal City, VA

Locus Robotics, Wilmington, MA
MassChallenge, Boston, MA
MassRobotics, Boston, MA
MITRE Corporation, Boston MA
NASA's Ames Research Center, Mountain View, CA
Naval Post Graduate School Spacecraft Robotics Laboratory, Monterey, CA
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Optimus Technologies, Pittsburgh, PA
Pison Technologies, Boston, MA
Rapid Flow Technologies, Pittsburgh, PA
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Riptide Autonomous Solutions, Boston, MA
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TORC Robotics, Blacksburg, VA
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Chunghwa Telecom (AI and Big Data Teams), Taipei, Taiwan
HIWIN, Taichung, Taiwan
Industrial Technology Research Institute of Taiwan, Zhudong, Taiwan
LINE Corporation, Taipei, Taiwan
Ministry of Science and Technology (AI Innovation Research), Hsinchu, Taiwan
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INTRODUCTION

Robotics and autonomous systems (RAS) are poised to dramatically impact the concept of technological superiority, a primary source of national power. Vilified in the entertainment media, detested by labor unions, and declared, "more dangerous than nuclear weapons," by industry magnates such as Elon Musk, our culture is just beginning to see RAS as enhancing our lives rather than threatening them.[1] But a tectonic shift in thinking in the last few years has placed RAS at the core of serious security and business strategies. When Advanced Research Projects Agency Network (ARPANET), the internet's precursor, was created no one could envision the way we communicate, educate, entertain, and work today. The revolution with RAS and artificial intelligence (AI) will be even more profound. Machine autonomy will expand human capability in ways that we cannot yet imagine—but need to be ready for.

An international competition in machine autonomy has begun and America's leadership in this race is crucial. In July 2017, the Chinese State Council announced their *New Generation Artificial Intelligence Development Plan* in which they made achieving AI a strategic priority. The Council articulated that the Chinese government's intent is to treat machine autonomy as the equivalent of the Apollo lunar missions. In doing so, China initiated a crash program that has economic and security ramifications for the world.[2] This is not a race that America can afford to lose, as even Vladimir Putin understands that, "Whoever becomes the leader in [AI] will become the ruler of the world."[3]

In the 2017 *National Security Strategy* and 2018 *National Defense Strategy*, the United States (U.S.) envisions a strategic environment, "characterized by overt challenges to the free and open international order and the re-emergence of long-term, strategic competition between nations." Both China and Russia are identified as revisionist powers employing *sharp power* and *hybrid warfare*, "to shape a world consistent with their authoritarian model—gaining veto authority over other nations' economic, diplomatic, and security decisions." Both nations have instituted government-directed programs to usurp America's digital supremacy and thereby initiated a contest that will rival the space race in the magnitude of its geo-political, economic, cultural, and security consequences. How can the U.S. realize machine autonomy in order to assure America's technological leadership, prosperity, and future security?

When one thinks about machine autonomy, one traditionally thinks of physical devices that are electrical or digital, but they are more than just the robot, drone, or algorithm. Machine autonomy should be seen as complex systems of systems and their practical development depends upon advancements in four enabling pillars: technology, society, governance, and industry. To date, there has been an unsynchronized approach to these pillars: technological innovation is disjointed, distributed across the country in nodes of ingenuity; formal education in appropriate Science Technology Engineering and Mathematics (STEM) fields is not keeping up with demand; an effective policy and governance dialogue has been slow to adapt or non-existent; and industry is diverging from national security interests. This lack of coherent development between these pillars undermines our ability to effectively harness the technologies for national security. Maintaining our role as a global superpower necessitates the formulation

of an AI national strategy to assure our technological competitive advantage. A coherent strategy will enable each pillar to support the other as technology develops. This will better empower the government to protect the rights, freedoms, and privacy of our citizens; it will also help our workforce and economy—a source of national strength.

Scope & Methodology

Over four months a diverse team of fifteen students, assisted by Eisenhower School faculty, conducted an analysis of the international robotics and autonomous systems industry segment to determine how America can maintain its lead in this burgeoning and highly competitive industry. The team's data collection methodology consisted of academic research, interviews with policy makers, discussions with subject matter experts, and select site visits in the U.S. and Taiwan. Intended for policy makers, this report informs and makes recommendations regarding how the U.S. can maintain its competitive advantage while simultaneously advancing strategic national security interests.

The report will open with brief definitions of the core technological concepts including autonomy, RAS, and AI—the last of which will be the focus of this report. Following are the highlights of an environmental scan using *Strengths, Weaknesses, Opportunity & Threats* (SWOT) framework to facilitate an understanding of the global context with respect to AI. This scan concludes that the hype in the media and fears of America soon losing its lead in AI development are overstated: the U.S. has the time to methodically organize AI development to account for not just technology, but societal and governmental impacts. A "deep dive" into the AI industry will follow investigating the state of the market using a *Six Forces Analysis* (a modified version of *Porter's Five Forces Analysis).* The goal with this analysis is to deconstruct the industry to identify challenges and opportunities as well as to graphically represent the present condition of competition. The analysis points to the industry structure driving firms' strategy, and firms may not be incentivized to develop technology useful for national security without more government input or demand. Maintaining America's competitive advantage is the cornerstone of this report and the focus of its second half. Proffered is a four-pillar model based on technology, society, governance, and industry with which government can integrate efforts to coherently develop AI. Our contention is that government's role should not be one of unequivocal support to the industry, but rather one of catalyzing—amplifying and accelerating—innovation. Following a brief conclusion are collated the most salient recommendations from the report, with suggested offices of primary interest.

Definitions

Definitions of "autonomy" abound.[4] Most definitions focus on labeling the robot, drone or AI itself, which is not particularly helpful in that it fails to take a system perspective. Autonomy is about more than just a description of what a machine can do by itself. More poignantly, autonomy manifests itself in multiple dimensions throughout a system. The nature of the task, degree to which the human exercises judgement, and how the AI relates to this environment needs to be understood in order to describe a system's autonomous nature.

Describing autonomy in mechanical systems crosses into philosophical disciplines and the combination of disciplines is still emerging.

RAS, "are interconnected, interactive, cognitive and physical tools, able to variously perceive their environments, reason about events, make or revise plans, and control their actions. They perform useful tasks for us in the real world, extending our capabilities, increasing our productivity and reducing our risks."[5] The industry surrounding RAS may be nascent but business is exploding. An essential element of any robotic autonomous system is the, an *animus* or logic that decides particular actions. All systems that demand a degree of autonomy require AI—their "killer app." After all, a robot is only as good as the intelligence that controls it.[6] AI is the fundamental driver of robotics and autonomous systems: it is a barometer of the industry and consequently merits in-depth study.

AI is, "the mechanisms underlying thought and intelligent behavior and their embodiment in machines."[7] To aid discussion, AI is generally thought of in three "calibers," and two "applications." The first caliber is Artificial Narrow Intelligence (ANI), also referred to as narrow AI or weak AI. It is an AI that specializes in one task. It can beat world champions at *Go*, it directs autonomous drones, and it manages your smart phone, but it cannot do all three. This is the level of all known AI today. Artificial General Intelligence (AGI), also referred to as human-level AI or strong AI, can perform any intellectual task a human can perform. This caliber of AI can reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience.[8] Artificial Superintelligence (ASI) is a digital intellect that is considerably smarter than a human in every regard. This is a machine that one would consider to exhibit astounding creativity, insight and the ability to solve humankind's greatest challenges and problems.[9] With respect to AI application or employment, specialists categorize them as either Cognitive Assistant AIs or Autonomous AIs.[10] Cognitive assistants work hand-in-hand with humans, sometimes quite literally (i.e. your smart phone) to directly augment human capacity. They are best thought of as existing in human-machine teams where they are proving superior to the most powerful computers or the most masterful humans.[11] Autonomous AI, on the other hand, exercises a degree of self-sufficiency and self-directedness due to isolation or to minimize response time. Industry's and defense's application of AI is rapidly changing our world. Understanding what is transpiring in this ecosystem starts with a detailed environmental scan.

THE STRATEGIC ENVIRONMENT (SWOT ANALYSIS)

The U.S. and China currently lead the world in AI research and product development. While many quantitative and qualitative indicators lead analysts to believe that in the next five years China will overtake the U.S. as the world's leader in AI, our analysis indicates that the US will retain a competitive advantage in several key areas that will take China more than a decade to overcome.[12]

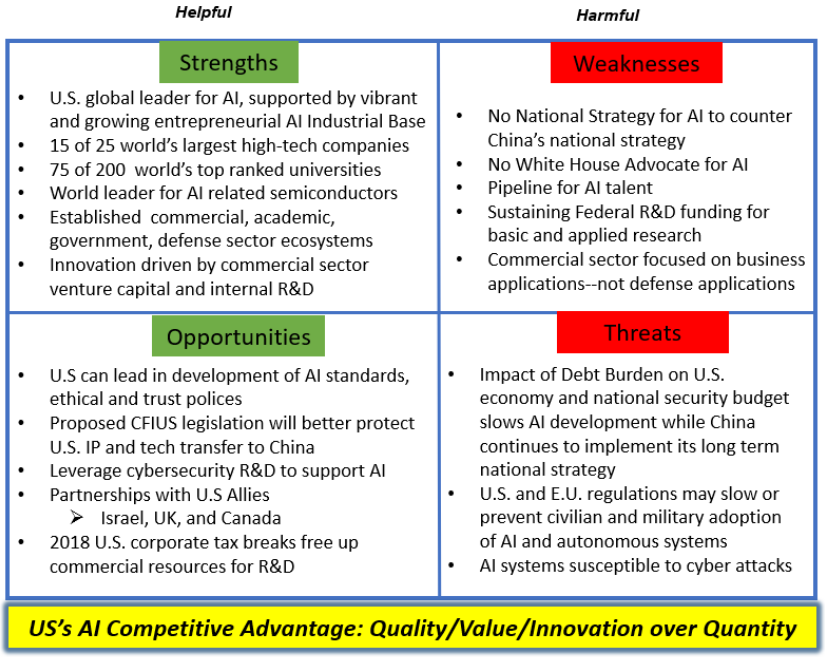


Figure 1. SWOT Analysis Summary

Strengths

Robust technology hubs, a rich assortment of world-class academic research institutions, highly-capable government-sponsored laboratories, and a free market economy mostly unfettered by government intervention provides the U.S. with an unmatched innovation ecosystem for AI leadership. In addition, world leadership in government research and development investment, particularly basic research and development, along with the resulting commercialization of AI technologies has proved invaluable to advancing the state of the art of AI technology in the U.S. High-profit potential, a burgeoning high-tech start-up environment, and massive investments by leading technology companies and venture capital funds provide fuel for a dominant U.S. commercial AI industry.

Weaknesses

Although the U.S *National Artificial Intelligence Research and Development Strategic Plan*, published in 2016, offers relevant recommendations, it falls short of providing a comprehensive national framework for AI, which will have far-reaching impacts across all facets of life in the coming decades, including employment, economic development, education, healthcare, and defense. There are fewer STEM graduates in the U.S., when compared to nations such as China and India, and immigration policies do not effectively attract or retain people with the high-technology skill sets necessary for AI research and development. This is a critical weakness in the decades ahead as the competition for AI primacy accelerates.[13]

Opportunities

AI, and its cross-cutting applicability with other technology areas such as advanced computing, "big data" analytics, biotechnology, and nanotechnology, offers vast new opportunities for economic development and the nation as a whole in areas ranging from healthcare to transportation to cyber security. Collaboration of AI technology efforts between the U.S. and other partner nations such as Israel, Canada and the United Kingdom, other global leaders in AI development, provides opportunities to accelerate AI development and acquire AI technologies that advance U.S. interests. In addition, changing attitudes towards the protection of U.S. intellectual property by the U.S. government will likely strengthen legal protections and greatly increase the scrutiny of acquisitions of U.S. technology companies by foreign entities. Additionally, the current trade war is damaging the Chinese high-tech sector, with analysists projecting that China may need a decade to catch up.[14] The U.S.' dominant position enables an influential role in defining AI interface standards, and ethical, trust and verification policies.

Threats

Nation state competition, from China in particular, is the primary threat to the U.S. AI technology base. Heavy Chinese government and venture capital investment in AI, ambitious Chinese government plans and support for AI development, the threat of Chinese intellectual property theft, and coercion of U.S. technology companies will make China problematic for the U.S. high-tech industry for the foreseeable future. Incessant cyber-based attacks also serve to exacerbate the threat of intellectual property theft. Another threat is the from the greater levels of computer-based autonomy in areas such as finance, healthcare, transportation and defense. Development of policy, technical controls, and ethics related to AI safety struggles to keep pace with the advancement of technology. This lack of safety and policy development compared to technological development could result in unintended consequences or harm that draw political and societal backlash and condemnation leading to a slowing of AI development and its associated benefits.

Strategic-level Deductions

The fear that the U.S. will lose its leadership position in AI to China is currently overstated, but there are risks that must be managed to avoid a weakening of America's competitive advantage. The U.S. has a diverse AI ecosystem and a long history of technology innovation bolstered by democratic values that powers the free-market entrepreneurial culture which China has not yet been able to replicate. This diversity and entrepreneurialism promotes adaptability and helps further enhance the ecosystem. Nevertheless, China has a long-term state-sponsored strategic plan to become the world's leader in AI. China's national focus, financial, and human capital resources present a serious and credible long-term threat to the U.S.' ability to retain its competitive advantage.

THE STATE OF THE INDUSTRY – SIX FORCES ANALYSIS

Need for Designation

Interestingly, no formal robotics, autonomous systems, or even AI industry exists. Regardless, these are economic activities which we need to watch closely. Researchers, developers, firms, and policy makers serious about developing machine autonomy characterize it as a capability—a technological innovation. This may be true, but robotics, autonomous systems, and AI in particular are at the point where they need to be recognized as an industry unto themselves. The establishment of an industry will enable the effective tracking of metrics, transparency, and visibility.

The North American Industry Classification System (NAICS) does not yet recognize this industry despite numerous small enterprises whose primary business activities come from the sales of autonomous systems, robots, their components, or algorithms. For large corporations, AI or autonomous systems consist of only a minor segment. Despite this, precedence exists to support the establishment of NAICS coding for such industries. One example is the computer industry. It too is an enabling, cross-cutting technology; yet, it has its own coding (33411) and breaks out into subordinate industries of manufacturers, chip designers, software writers, and peripherals. Robotics, autonomous systems, and AI merit the same structure to allow for comparability in business statistics which are critical to enabling government to develop effective policy.

Industry Definition

The structure in which AI firms do business is comparable to that of software developers and parallels can be drawn to parse the nuances of their unofficial industry. Therefore, we offer the following industry definition: AI developers disseminate licenses to customers for artificial intelligence and the right to execute that AI on their systems. Firms in this industry design, develop, distribute and may provide support material and support services to AI. What follows is a *Six-Factor Structural Analysis* to bring more fidelity to understanding this burgeoning industry.[15]

Rivalry Among Existing AI Competitors

HIGH. The industry consists of a relatively small group of corporations and subsidiaries. There are few enough firms that the industry is comparable to an oligarchy. Production limits are nowhere near being reached, and AI is generally perceived as a "wide-open frontier," making it a potentially lucrative industry for those able to participate. Barriers to exit are low. Some firms have developed proprietary chips sets, and all have invested significantly in code, but either of these investments would be readily acquired by competitors if a firm wished to leave. This is a peculiar industry as these rivals are irrationally committed—there is an intense competition in research and development, but there is no price competition amongst them which contributes significantly to profitability.

Threat of New AI Entrants

VERY LOW. The high costs of entry into AI development are very dissuasive and the situation is worsening. The assembly of artificial neural networks and their training is labor intensive. This assembly demands more than just skilled programmers—it demands computer scientist and engineers with exceptionally strong mathematics skills. In interviews with American firms, these individuals have been colloquially referred to as *unicorns* because they are so hard to find. Research and development is critical and expensive. The current trend is for large companies to acquire intellectual property through the purchase of the firm that originated it; hence small firms are barely getting past incubation. Brand names are just beginning to emerge, forming a weak monopoly. AI development is creating a virtuous cycle allowing companies that are successful to generate more data, improve their services, and attract more customers. That sounds like a good thing, but it could also lead to more corporate concentration and monopoly—as has already happened in the software and information technology sector.[16]

Bargaining Power of Suppliers

VERY HIGH. Three inputs are required to realize AI: human talent, powerful processors, and voluminous data.[17] It is no coincidence that the primary players in AI development are those companies that have access to large amounts of data via the internet, mobile phone services, or cloud computing. In this regard most are vertically integrated, either by themselves or via parent companies. The human capital necessary to develop AI is a considerably different story.

Talent is unique and scarce. Human capital is a significant factor and its management is critical to a firm's success. There is no single industry supplier of labor because the latest advanced applications in machine learning are so different from standard software development that the talent pool is miniscule. The paucity is so severe that major corporations are offering salaries comparable to NFL starting quarterbacks to attract top machine learning talent.[18] Firms we visited reported a national bidding war ongoing and they confirmed that salaries for the best in the field were stratospheric. Switching costs work very much in labor's favor. The effect on the industry is the equivalent of powerful suppliers who can insist on higher prices and more favorable terms, thereby having a negative effect on firm profit. Equally significant to AI is the hardware.

AI requires particularly powerful processing chips. So much so, that firms are either forced to produce them themselves or forced to buy them from a select group of suppliers. This specialized group forms a unique sub-oligarchy in the industry.[19] There is significant differentiation between the chips developed by the premier suppliers that permit them to charge higher prices. Hence, pitting one against the other to lower chip costs is nearly impossible. The costs are clearly substantial, but sometimes worth the investment to avoid to avoid exorbitant cost—evidenced in one corporation creating their own neural network chip last year.[20]

A steady supply of well-structured data is also essential for machine learning and the training of AI. Presently, scientists advance AI via "deep learning."[21] This demands massive

amounts of clean and well-organized data.[22] America generates a great amount of data, but China captures more. While China trails in research, quality algorithms, hardware, and commercialization. Credit Suisse predicts China is a contender in the artificial general intelligence race based solely on their access to un-regulated data.[23] Unresolved issues of data gathering and data privacy in both the U.S. and Europe places firms operating in those countries at a disadvantage compared with firms operating in less restricted countries such as China or Russia.

With these upstream costs being so prohibitive, the question begs, "How can a company make money in this industry?" The answer lies in the lack of power attributed to buyers.

Bargaining Power of Buyers

VERY LOW. AI is rapidly changing the world, and everyone wants it. It has applicability among most industries: aerospace, agriculture, consulting, defense, energy, entertainment, financial services, health services, infrastructure, logistics, manufacturing, and transportation in particular stand to benefit. The list of buyers and potential buyers accumulates very quickly. Interestingly, they are very discerning about the product—after all lives may depend upon the quality of the AI. Consequently, users are not yet overly price sensitive.

Marketing of AI has been intense and resulted in the mistaken belief amongst non-tech firms that it is a panacea; that it is as easy to install as the latest software update. AI systems demand a thorough preparation of data, intense monitoring of algorithms, and a lot of customization to be useful.[24] Many buyers are simply not sophisticated, which undermines their power as a group. But AI is more than just an economic race—it is a national security one too. Consequently, the Department of Defense (DoD) has a vested interested in AI, but the challenge is that the DoD's power as a buyer of cutting-edge technology has eroded.

DoD's bargaining power is no better than other buyers but for different reasons. Most AI firms thrive on venture capital or public-offering funding; they do not want to work with government unless they can make substantial margins—margins unpalatable to the current acquisition enterprise. Money like that cannot be made with one-use systems that are typically developed by defense. Additionally, during our visits we encountered a common theme among young entrepreneurs—that they find the bureaucracy and accountability of government contracts stifling and are losing interest in pursuing work with defense. This paradigm undermines the DoD's power as a buyer in high-tech domains in general.

Threat of Substitution

VERY LOW. Substitution is only possible in an environment where alternatives exist to acquire a comparable product. There are none in the AI market. Costs to switch from one AI to another AI are exorbitant. There are no cheap options and piracy is non-existent. Installation of an AI system is not like buying the latest version of a software and hitting "Install." It is more akin to the revamp of a full enterprise system—all business processes must be re-engineered. And more importantly: not all AI is fungible.

Lack of Complementors

VERY LOW. No one buys a computer without software and no one buys a robot, drone, or self-driving car without AI. These goods, and the AI that makes them function, are complements and they are expanding exponentially.[25] This trend will continue for the long term. Even small firms push the boundaries by bringing autonomy to the mundane with AI: some enable robotic co-pilots in small aircraft cockpits, and others deliver autonomy to earthmovers.[26] There is no shortage of complements, and consequently opportunity abounds—as does potential profit.

Industry-level Deductions

The graphical representation of the *Six-factor Analysis* manifests a relatively small polygon. Government economists would prefer that polygon to be as large as possible; this would represent a highly competitive environment. As you can see, the polygon is quite small, which is just the way industry likes it—profitability for the largest developers of AI is very high. Observations in behaviors of large firms reinforce this analysis: the equity markets are the engines of AI development. Therefore, a key lever to influencing the acceleration of development is by affecting the behavior of equity markets.

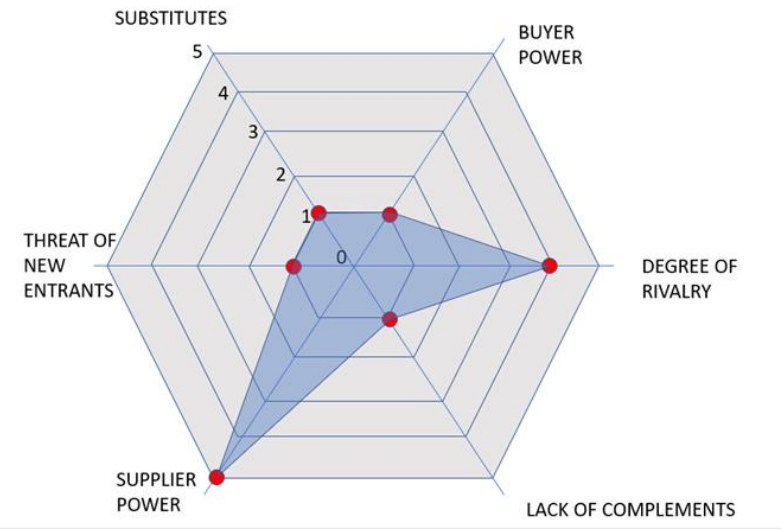


Figure 2. Graphical Representation of the Six-Factor Structural Analysis

The structure of the industry drives disparate strategies between large and small firms. Among the small firms we interviewed, almost without exception, their strategy was to be bought out by large firms. Large firms assume less strategic risk and focus on cost efficiencies. They innovate by acquiring small firms. The effect is telling on the ecosystem; there are precious few medium-level businesses resulting in less diversity which has the potential to erode competitiveness in the long term.

Technology is converging but the defense and commercial sectors are diverging. In the absence of a demand signal from government, the commercial sector is driving innovation to their ends—not necessarily toward what would be useful for national defense. Strategic-level organization is imperative to generate a demand signal to this industry in order to capitalize on the technologies for national defense.

MAINTAINING THE COMPETITIVE ADVANTAGE

One would be short sighted to imagine that maintenance of competitive advantage entails an exclusive focus on technology development. To advance a disruptive technology, a nation must not focus solely on the technology, but rather should adopt a broader approach by preparing the society, governing the technology to an appropriate degree, and catalyzing the industry. Being a leader in AI demands such an holistic approach, one that incorporates these three pillars as well as technology development. Each pillar will be analyzed in turn with an emphasis on their contribution in maintaining America's competitive advantage.

Technology

Since the 1950s, industry, academia, and sovereign funds have been used to build on AI technologies and the ecosystems these tools require to operate (Appendix B). Progress has been most fruitful at the convergence of all three, where resources can be spread across multiple areas to foster unique forums were competition and collaboration thrive. Although AI will dominate industries in the future, most companies do not have the capacity to support the current competition as well as simultaneously pursuing "moon shot" efforts. We are observing this in the autonomous vehicle market, where billions of investment dollars are being pushed towards applied research activities at the expense of needed basic research. Companies are trying be first to market by perfecting the marriage of algorithms with the 10-year-old technology of light detection and ranging (LIDAR) sensors vice the newly applied "sight perception" methodologies.[27]

To accelerate America's AI technology approach beyond the corporate profitability focus, the government must establish a national fund to sponsor the best practices across research, development, and innovation. This is another "first to the moon" moment, requiring centralized leadership. Federal funds can be leveraged to mitigate the need to achieve profitability in the near-term, providing industry incentive with the best interest rates on capital. In addition, investments can be multiplied across basic research areas for both the foundational tools as well as the software platforms realizing AI. Quantity of effort becomes an advantage for the nation, with winners and losers not determined as early as they are by commercial markets. Enabling basic research will also help grow the U.S. educated AI base, ensuring the nation has the necessary human resources in the future. Furthermore, a centralized fund enables structured data to be created solely for AI development, which is a key enabler for system learning. Industries to include financial firms, medical care and defense, where structured data is commonplace, can act as the initial test beds. This will provide the U.S. an ability to better understand how neural networks operate as well as ingest information. If we understand how the systems learn and operate, we theoretically can manage to prevent a point of no return.

Society

Culture. Fear, excitement, and uncertainty are the sentiments that best describe the western world's attitude towards robotics and autonomous machines. Oscar Wilde once opined that, "Life imitates Art far more than Art imitates Life," and nowhere is this more evident than in

the role of cinema and literature in shaping these emotions over the last four decades.[28] The dread and disdain of Hollywood's humanoid *Terminator,* created to exterminate us, versus *Big Hero 6*'s puffy medical-robot-cum-superhero gave Americans both something to fear and something to love. But generally, Americans maintain an apprehensive attitude regarding AI and are uncertain of what the future holds. Few can ignore the ominous warnings of famed physicist Stephen Hawking who admonished us: "In contrast to our intellect, computers double their performance every eighteen months. So, the danger is real that they could develop intelligence and take over the world."[29] Unlike so many other cultures, here, the specter of Dr. Frankenstein looms. We believe we risk compromising our humanity and being destroyed by our own creation. Acceptance of AI demands a change in our cultural norms and a realization that technology will not destroy mankind, but rather enhance our lives: technology serves those who use it.

In a recent study by Pew Research Center, 67% of Americans surveyed expressed more concern than enthusiasm about androids and digital automation, specifically in a future where robots and computers replace humans' jobs.[30] Americans are more comfortable when machines perform in accordance to their designed programming and less so when machines learn and adapt to changing conditions. Many manufacturing jobs have already been replaced by automation, but the scope of autonomous machines replacing humans may be much larger. Soon, bookkeepers, clerks, accountants, salespeople, and customer service representatives may find their jobs performed by a machine. The majority of Americans have expressed worry about machines doing jobs currently done by humans: 73% of Americans surveyed expressed some level of worry that robots and computers could do many of the jobs currently done by humans. These numbers do not bode well for the acceptance of an inevitable technology, particularly one with which we may have to become quite intimate.

Robots are currently being created to care of our aging population. However, Americans have not embraced the idea of robot companions and are mostly unaware of emerging robot applications. In fact, 65% of Americans surveyed are completely unaware of robot caregivers, with 47% of the respondents expressing some level of worry.[31] The thought that technology-loving Americans would express concern about robots who would care for the elderly is counter-intuitive. The geriatric-care industry is projected to be chronically short of caregivers as the Baby Boomers age, and the elderly stand to benefit considerably from these robots, but they have historically shown lower levels of interest in adopting new technology and internet use.[32]

When employers use AI to evaluate job applicants, Americans are rather skeptical: 76% of Americans would not knowingly apply for a position in which a computer program evaluates applicants.[33] A broader indicator of our distrust is that 92% of Americans expressed some level of worry in the use of hiring algorithms that use AI.[34] We do not trust the ones and zeros that dictate who to hire because we believe these algorithms cannot evaluate personality traits important to humans such as work ethic, judgement, compassion, etc. Our society's opinion is that these traits can only be determined in a face-to-face interview.

The rate of technological change already outpaces the rate of cultural acceptance of robotics and autonomous systems, and this phenomenon is generating social anxiety. The solution requires a whole-of-nation approach that seeks to bolster the U.S. competitive advantage

in global markets, assisting those who may lose jobs to automation by providing training and education in high-demand career fields related to AI, robotics and autonomous systems. Sound policy changes and government incentives would mitigate fear and possibly even become a catalyst for a more rapid cultural acceptance in America.

Education. Even as AI will put some employees out of work, the industry will generate new jobs, but these new jobs will demand further education and training as much of it knowledge based.[35] Only the nature of human work is going to change, not its volume. Much has already been said with respect to the challenges facing the future labor force in our environmental scan, but two topics demand amplification: the restructure of the workforce pipeline and winning the war for educational talent.

AI will force a fundamental change of the education system.[36] "Generally speaking, the educational system in the U.S.—both K-12 and college—focuses primarily on training to master convergent thinking…yet this is precisely the sort of thinking that increasingly is a robot's specialty."[37] Excellent at instructing general skills, the current system must complement instruction with more technical and adaptive skills.[38] Learning a second language may not be as important as learning a machine language in the near future. Computer science degrees will not be essential, but the ability to work with advanced machines, understand computational processes, and comprehend data analytics will.[39]

The workers who command the highest wages on the market today are those not just with advanced degrees, but with degrees that enable them to work with or alongside intelligent machines.[40] Human-machine teams are proving that effective teaming is more important than either master-level human skill or AI alone.[41] In the current environment, competitive advantage will flow to the nation that can best integrate human-machine teams, and this will hinge on instilling the workforce with more adaptive skills.

Winning the war for talent is imperative. Replenishing the ranks of universities' robotics and AI professors as they get lost to higher paying industry jobs, is proving increasingly challenging. These professors are critical because they are responsible for graduating thousands of experts every year.[42] Dr. Andrew Moore, the Dean of Carnegie-Mellon's school of Computer Science proposes such innovative ideas as expanding fellowships, multi-year awards to the top 100 researchers to enable them to continue their academic research careers, and broadening multi-year, broad-based research awards.[43] Every professor that key universities lose to industry narrows the workforce pipeline. What America needs is precisely the opposite, and the only means by which to combat the astronomical salaries offered by industry is appropriate incentivization, such as Dr. Moore proposes, to keep professors in universities.

Governance

In his 1950 book entitled *I, Robot*, Isaac Asimov made famous his "Three Laws of Robotics." In subsequent novels these laws guided robot-human interaction for millennia. Such a long-term policy is—fiction—rather, America needs something that can affect the near term because AI technology is advancing faster than policy's ability to cope with it. America has a

penchant for entrepreneurial freedom vice dirigisme, so rather than taking the path of diktats and bans we would benefit from a national discussion and ultimately guidelines on data privacy, explainable AI, and safety.[44] Trust in AI application should be a primary consideration when developing policy in this industry.

Data Privacy. Presently, ethical implications of the technologies in AI and robotics are not well debated or agreed upon.[45] The pace of technological advance is so fast that rarely do developers stop to think of the repercussions of disruptive technologies such as AI because the debate would slow them down. But AI comes with long-lasting moral challenges for our polity, economy, and society. Each of us is already using AI; it is on your smartphone, and it is collecting data on you, and that data is invaluable to developers, and they are loath to relinquish it. Is your privacy a human right? What are the implication for national security? This discussion needs to be more robust with the focus of making smart policy.

The European Union is currently enacting the General Data Protection Regulation. Where America leans towards industry self-regulation, the European bent is very human centric, and this is reflected in the EU's heavy regulation. The failings of the self-regulatory approach are evidenced in the testimony before Congress this year regarding data privacy.[46] Parts of the General Data Protection Regulation are at odds with American rights to free speech, but it has merits as a template for discussion.[47] A balance must be struck between privacy rules that prevent firms from innovating and the protection of the privacy of citizens. Delaying will impact consumer confidence, eroding the long-term health of AI firms and societal acceptance.

Explainability. AI has been likened to a black box—once trained its inner workings are unknowable and mostly unexplainable.[48] The only aspect of their function knowable to humans is their input and their outputs. Today's personal digital assistants may sound female, but their code was developed by a male-dominated, culturally homogenous team; thus, there is potential bias baked into those AIs.[49] Being digital personal assistants, the risk they pose is likely not grave but other AI have already demonstrated biases in parole recommendations, loan applications, and job hirings which are arguably very consequential to individuals.[50]

As one industry leader told us: "Predictability is more important than controllability [in autonomous systems]." Essentially, he was driving at what has become known as *explainability* in AI. Explainability builds *calibrated trust* in users.[51] Two developments in this regard merit mention. The first is a *Turing Box*, designed by a group of researchers at the Massachusetts Institute of Technology. Modelled on B.F. Skinner's box with which he tested behavioral conditioning on animals, this "box" is actually software that a tester can upload into an AI to test for potentially harmful flaws and biases.[52] A second option that developers can use to build transparency and trust is via the block chain. "The blockchain provides one example of how a human ideal—i.e. trust—can be translated into mathematics and code."[53] Blockchain would enable developers to build a shared, incorruptible view of their world. If the group perceives another developer as violating the norms, breaking the rules, or exhibiting nefarious intent, the collective negotiates and agrees to a response.[54] Blockchain has the potential to instill self-regulation in the AI community and realize the trust demanded of western culture.

Safety. Confidence of the public for the mass adoption of autonomous machines will depend on the safety of the device. The salience of safety concerns was proven in 2018 when an experimental autonomous car was involved in a fatal accident in Arizona. This was the first instance of an autonomous automobile crash that resulted in a pedestrian death.[55] The national response was visceral. Prior to this incident, autonomous systems have covered over eight million miles combined, without incident.[56] During approximately the same period over 40,000 people died in automobile fatalities; precious few merited front-page coverage.[57] Alternatively, attribution of fault is a difficult societal problem with autonomous systems. Should the developer, computer coder or safety driver be charged with manslaughter?

The federal government has been slow in enacting legislation relating to autonomous vehicles. The delay in federal legislation has prompted states to take matters into their own hands. To date, 21 states have passed legislation and 11 states have issued executive orders related to autonomous vehicles.[58] The House of Representatives did pass a bill in 2017 but the Senate has yet to vote on its version of the bill. The primary challenge with the lack of legislation is that automobile manufactures have no mechanism to get exemptions to safety standards for items that do not apply to autonomous cars.[59]

The federal government is responsible for determining safety standards and the states have the responsibility over the operation of the vehicle. The use of autonomous vehicles is fundamentally different than a human operated vehicle, so this situation is rife with unintended lack of direction with respect to a fast-moving technology. To date, a few states have taken the lead on passing legislation in absence of federal legislation and the longer the trend continues the harder it will be to reverse the chaos of each state passing different legislation. Alternatively, the benefit of this system is that it will generate 50 different precedents; the federal government should be able to pick from one.

In the absence of federal legislation, The National Highway Traffic Safety Administration has been proactive in recognizing the rapid development of autonomous vehicle technology and issued a national autonomous vehicles policy in 2016. The 2016 policy guidance is forward-thinking and designed for autonomous vehicles that operate at Society of Automotive Engineers (SAE) vehicle automation levels 3-5 (Appendix C). The policy additionally directs that autonomous car manufactures ensure their vehicles meet the existing federal safety requirements mandated for traditional vehicles.[60] This is sound and forward-oriented regulation that serves as a good example for other policy makers.

Isaac Asimov is less known for another quote more relevant to our situation today: "Science gathers knowledge faster than society gathers wisdom." Currently our knowledge is ahead of our wisdom, but with an increased focus on data privacy, explainability, and safety this relationship can be put back into balance.

Industry

Last year, corporations worldwide spent $21.8 billion on mergers and acquisitions related to AI. This is 26 times more than in 2015 placing them where the computer industry was approximately 30 years ago.[61] Since their creation, personal computers have found a place in

over 87% in American households.[62] Their presence in the workplace is ubiquitous and within a generation, AI will be the same. The coming AI eruption will be so disruptive that government may wish to influence its direction.

At the strategic level, the U.S. has to determine how interventionist it wants to be. America has long been a paragon of limited government. The underlying assumption is that entrepreneurs, driven by the profit motive will generate natural economic growth.[63] Based on our consultation with industry, this paradigm needs to be reconsidered regarding autonomous machines, and the government should specifically support the technology of AI. The best tool with which to analyze the problem is Michael Porter's *Determinants of National Advantage* comprising four factors: *Firm Strategy, Structure & Rivalry*; *Demand Conditions; Related & Supporting Industries*; and finally *Factor Conditions*.[64] Although his model is one of description, one can arguably use it for prescription.

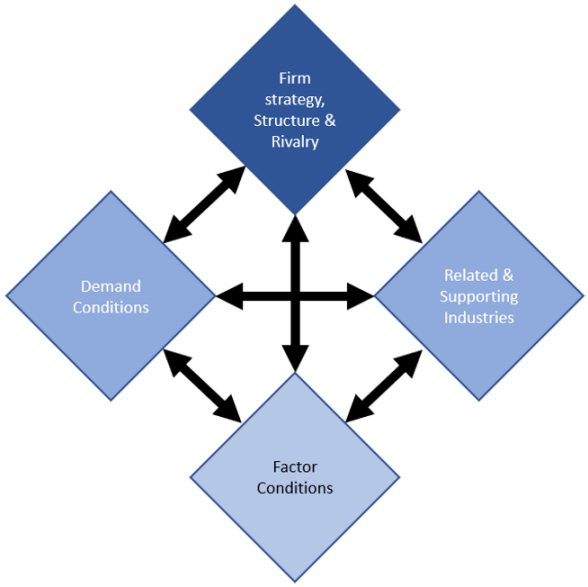


Figure 3. Porter's Determinants of National Competitive Advantage

Firm Strategy, Structure & Rivalry.[65] Since World War II, the U.S. has a history of competing based on high compensation (i.e. wages) and high innovation, but in the 2000's American industry drifted towards competing on costs—focusing on limiting investment in key factors of production such as capital, workforce skills, and research and development to keep wages low.[66] This is antithetical to America's recipe for success. Herein is the source of the perceived divergence between government and industry with respect to AI. In a period where government, DoD in particular, sees the need for significant investment in AI, industry continues to seek a guaranteed return on investment: the government wants innovations and value; corporations want low costs and profit. Government could continue to follow industry's lead and pay market rates for AI, but doing so may preclude the development of single-use AI applications for security and defense. To influence this dynamic, government must lean toward a policy more to the right on the *Continuum of Government-Market Engagement,* toward a more directed policy so as to enable alignment. By doing so the government will influence the structure of the market and drive change in firms' strategy. Supporting industry in this context does not entail government coddling, but rather government challenging the industry to spur innovation.

The industry is replete with rivals and the right government incentivization can intensify innovation in areas that have the potential to enhance national security. A means by which governments could create the desired mindset is via inducement prizes, which powerfully

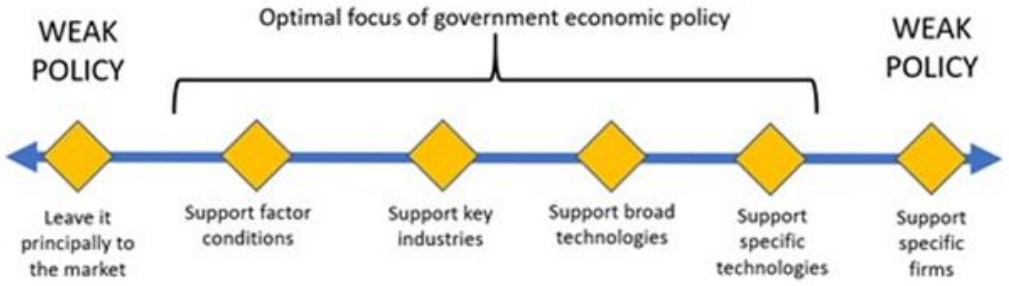


Figure 4. Continuum of Government-Market Engagement. Credit: adapted from Robert D. Atkinson, "The Competitive Edge: A Policymaker's Guide to Developing a National Strategy," December 2017.

incentivize rivalry.[67] Prize competitions in AI would encourage innovation well beyond our patent system. The good news for governments is that firms are not necessarily motivated by purely financial prizes. Take for example the *XPrize* for sub-orbital spaceflight: twenty-six teams competed for a ten-million-dollar prize, yet collectively spent over $100 million of their own money in development.[68] This was clearly potent incentivization. Why would firms engage in this behavior? Because they benefit from the seal of quality ascribed to their achievement when selling or licensing their technologies to a degree well beyond what can achieve through marketing.[69] Of eight active *XPrize* competitions, one relates to AI, but at *Challenges.gov* there are only two out of 835 such prizes. An opportunity is being missed here. Government needs to capitalize on this powerful phenomenon—the return on investment can be exponential. Inducement prizes will increase the degree of rivalry in the industry and the availability of substitutes, thereby making the industry more competitive—effectively increasing the area of the Six Forces polygon.

Demand Conditions.[70] A recurring theme in this industry is that they are not getting a demand signal from the government. The industry is rudderless in the application of AI to security and defense. Part of the problem is that the defense team has fallen prey to what many buyers in this market have—that technology is moving so fast that it is hard to keep up the understanding of AI technology in order to be smart customers, but this can be rectified by creating an AI champion and using the DoD as an integrator.

AI does not have a home in the DoD and as a consequence, development is disparate.[71] Development would benefit from coherence. The role of a government acting as an integrator is a tried and true methodology. Taiwan's development of its homegrown research and technology organization, the Industrial Technology Research Institute (ITRI), serves as an example. One of ITRI's most notable successes was with its notebook personal computer project. "In this case, the ITRI developed draft specifications for a common machine architecture."[72] With a common architecture in place, "a prototype was developed and translated into a series of standardized components that could be mass-produced by Taiwanese manufacturers."[73] This project catapulted them to a position of global competitiveness in the notebook market. While

sponsored by the government, ITRI is led by industry—the arrangement capitalizes on the strengths of both. With uniform standards driving requirements and specifications, Taiwan became the technological leader for personal computer manufacturing.

This is similar to the American experience at the beginning of the 20th century. With the emerging industries of the second industrial revolution, the U.S. government chose to team with industry to facilitate growth, innovation and success.[74] We need to consider how to do this again in the 21st century. The key similarity in both examples is that industry and government collaborated to synchronize policies across industries to make smart domestic customers and create sophisticated demand. The U.S. is flush with existing research and technology organizations such as the Federally Funded Research and Development Centers (FFRDCs) and University Affiliated Research Centers (UARCs). DoD can work with the FFRCs to encourage integration to better understand the environment and synchronize policies across technology, industry, and society to maintain and improve America's competitive advantage. A national champion and high-level integration will create a coherent signal and generate sophisticated demand for security-related autonomous systems and AI. Such an initiative would change the profile of domestic demand in that DoD would evolve to be a more sophisticated and discerning customer making the ecosystem more competitive and innovative.

Related & Supporting Industries.[75] Competitive advantage accrues with innovation, and there are multiple paths by which industry innovates, two of the most typical being science or engineering. Historically, the U.S. economy has thrived globally thanks to its strong science and basic research capability. Arguably one of the most powerful tools behind the scientific defense research program, and the biggest weapon of defense innovation in America, has been the Defense Advanced Research Projects Agency (DARPA).

The U.S. government's aim in bolstering the nascent AI industry must not be to solve the technical problems but rather to empower the ecosystem, and this is precisely what DARPA does; the DoD can leverage this. Other nations have tried to emulate DARPA but to no avail. That is because they focus on copying methods, but DARPA is more than a methodology. In DARPA incentives, motives, and resources are all aligned making it a puissant provider of knowledge to the nation. Through DARPA, government focuses the basic research of academics, industry, and government partners. Tampering with this relationship would undermine the ecosystem. Conversely, feeding this relationship would commensurately energize the ecosystem. Intelligence Advanced Research Projects Activity (IARPA) works in a similar manner and promotes comparable research. The Government supercharging both DARPA and IARPA would result in acceleration of innovation writ large within the U.S., from which AI development would be certain to benefit. This initiative would have the additional benefit of generating more complements as the technology proliferates to other uses. With more complements come more competition which serves to ultimately increase America's competitive advantage in AI.

Factor Conditions.[76] Arguably the most important determinant in the successful development of technology is *Factor Conditions*. Classical trade theory posits that endowments such as land, natural resources, labor, and capital determine how and what a nation trades—these are its *factors*.[77] Possibly the most powerful means by which to spur innovation in machine

learning pertains to this last factor, capital, and its generation. Rather than broad spectrum tax breaks, the federal government should offer a tax incentive to long-term capital gains, restricted to corporate equities of AI, robotics, and autonomous system firms.[78] Incentives such as this are a magnet for venture capitalists and funds pursuing aggressive growth strategies. Capital gains tax incentives would supercharge interest in the technology and sustain long-term investment in AI in America. Ultimately, it would draw more new entrants into the industry, creating more rivalry, and more competition in a virtuous cycle—increasing the area of the Six Forces polygon—until government achieves an acceptable balance between competition and profitability.

Government's role in developing the nascent AI industry is not one of succor, but rather one of catalyzing. Only a strong domestic market keeps firms international competitive. Government can create the conditions to achieve this through inducement prizes, federal-level integration, energizing the AI ecosystem, and incentivizing capital migration to AI.

CONCLUSION

AI is a potent source of national power that impacts U.S. national security. Our competitors are focusing their efforts to contest our technological edge but are less hindered by governance, even if that governance comes with heavier hand. We must diligently plot our course and focus our efforts with deliberate thought to ensure we maintain our edge and our ethics.

AI has the ability to strengthen U.S. security not only by helping to protect our citizen's freedoms, privacy and physical security, but also to increase workforce productivity and the economy. Currently the U.S. is leading the world in AI development from a technology perspective. America's competitive advantage is this field is, and has always been, an innovative, value-added approach but direction, policy and governance are lagging and threaten to retard development. The U.S. needs to build trust in our AI systems. We must also build trust in our systemic approach to implementation, with open, practical policy and governance development. Overall, AI development needs to be addressed more comprehensively.

To maintain a competitive advantage over todays near peers, the U.S. needs a coherent national strategy to integrate the science, technology and development that supports machine autonomy and intelligence. A coherent strategy will foment a national vision to empower and strengthen the virtuous cycle between industry, academia, society, and government.

RECOMMENDATIONS

Department of Defense

Recommendation 1: Assistant Secretary of Defense Research and Engineering (ASD(R&E)) should be designated the lead for all things AI and create an integrated *Department of Defense Artificial Intelligence Strategy* for the development and application of autonomous systems and

artificial intelligence. The strategy should be in coordination with interagencies, industry, and academia. Each Service should designate a lead proponent in developing this strategy and provide prioritization of resources for future technological advances in these areas.

Recommendation 1a: Under the DoD AI Strategy, ASD(R&E) should outline the framework for continual assessment of activities within DoD and leverage disruptive technology that is developed in the commercial sector. Other priority areas that should be closely monitored include autonomous AI and human-AI teaming.

Recommendation 1b: Under the DoD AI Strategy, ASD(R&E) should provide oversight to ensure disruptive technologies are quickly transitioned to Defense Laboratories and/or the Services in order to maintain, "innovation at the speed of relevance."

Recommendation 1c: Under the DoD AI Strategy, ASD(R&E)'s scope of responsibility should be expanded by integrating public and private sector investments through DoD sponsored accelerator and incubator programs with special emphasis on dual-use technology.

Recommendation 2: DoD should significantly increase funding to Defense-wide research and development, specifically focused on advanced technology weapons and autonomous systems. DoD should also conduct a review of all existing weapons platforms to determine duplicity between legacy systems and fielded advanced technology. Redundant capabilities should be reviewed to determine if programs should be stopped due as advanced technology weapons are expected to provide greater lethality while significantly decreasing force structure and costs.

Other U.S. Government Agencies

Recommendation 3: Office of Science and Technology Policy (OSTP) should leverage the existing *National Artificial Intelligence Research and Development Strategic Plan* and the *Preparing for the Future of Artificial Intelligence Report* in order to develop a broader *National Artificial Intelligence Strategy* in which research and development is only a subset of the whole.

Recommendation 3a: Under the National AI Strategy, OSTP should outline a framework for continuous assessment and resource strategy that is integrated into the annual President's Budget in order to ensure the U.S. competitive advantage does not erode and to take advantage of the opportunities, mitigating weaknesses and threats before they have material impacts.

Recommendation 4: OSTP in coordination with interagency, industry, and academia should establish a *National Code of Conduct for Artificial Intelligence* which describes nationally accepted definitions related to robotics, autonomous systems, and AI. This Code of Conduct will also define ethical, legal, and social implications, outline acceptable use and application of these technologies. Other areas that should be included are: machine learning, big data, cloud, quantum computing, and the use of autonomous lethal weapons in support of national security. A National Code of Conduct for AI should also potentially be the starting point for an International Code of Conduct for AI that would be vetted through the United Nations, with the U.S. as the lead.

Recommendation 5: OSTP in coordination with the Department of Education, academia and industry leaders should develop initiatives that address gaps in developing world-leading AI researchers, practitioners, and educators. OSTP should expand the scope of government internships in order to attract talented students into the federal government.

Recommendation 5a: The Department of Education should increase federal funding for STEM grants, scholarships, and other programs while reducing funding in career fields that will likely be replaced by autonomous systems such as accounting, healthcare, and other business-related fields.

Recommendation 5b: The Department of Education and the Department of State in coordination with universities and industry leaders should identify critical workforce shortages and create an initiative offering permanent residency and a possible pathway to citizenship for qualified foreign students.

Recommendation 6: OSTP should establish an interagency committee to review and recommend any available opportunities to use challenges or competitions (e.g. DARPA Challenges) to spur development efforts towards areas of national need. The committee would identify needs at the macro-level and make recommendations whether sufficient technical maturity exists in particular sectors to initiate a challenge.

Recommendation 7: Congress should be an active champion of new robotics and AI technologies through incentivizing innovation, protecting intellectual property and minimizing regulatory constraints. Potential actions include: 1) increase funding for basic research at U.S. universities and federal laboratories, 2) use the Production Tax Credit (PTC) and Investment Tax Credit (ITC) to incentivize robotics and AI development in a similar fashion that incentivized the U.S. renewable energy industry 3) use sanctions or other tools of national influence from the U.S. and partners to pressure nations to reduce incidents of intellectual property theft, and 4) minimize regulations that inhibit new technologies from being more commercially available and viable.

APPENDIX A - STRENGTHS, WEAKNESSES, OPPORTUNITIES, & THREATS

Strengths

The U.S. has a vibrant and growing AI industrial base supported by a well-established, broadly experienced aerospace, information technology, and defense sector. America's free-market economy, supported by government policies and a world-class education system, has created an innovation ecosystem that produces both technical giants and small startups that allows us to continue to lead the world in innovation.

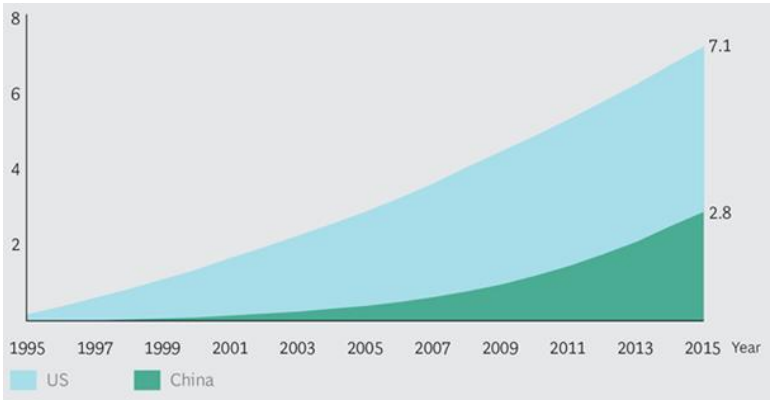


Figure A1. Cumulative R&D expenditures in trillions of dollars. Credit: National Science Board, Science and Engineering Indicators 2016.

Today, most of the AI advances in the U.S. are occurring in the private sector and academia. Gartner research found that, "The U.S. is driving AI across the spectrum in software and hardware. Early use cases, early adopters—it's happening in the U.S. more than [in] any [other] geography."[79] Furthermore, an April 2017 McKinsey Global Institute report found that the U.S. has a more robust AI start-up community than China. Their analysis identified 39 promising start-ups compared to only three for China.[80] Additionally, America has the competitive advantage over China in other critical complementary areas such as system integration, algorithm development, advanced microcircuits, and information theory. The U.S. has a robust and innovative semiconductor industry and although China is making massive investments, its semiconductor industry lags behind the U.S. American-owned companies, are the dominant suppliers of AI and special purpose semiconductors.[81] A November 2017 *Investor Business Daily* analysis assessed that China has a major weakness in high performance semiconductors which will impact their ability to compete and emphasize that China is nowhere close to catching up to the U.S.[82]

Moreover, according to the 2018 National Science Foundation's, Science and Technology Indicators Report the U.S. still leads the world in research and development funding, but China does follow closely behind.[83] China allocates its research and development dollars differently than the U.S. America spends close to a third of its research and development investment on basic and applied research.[84] China by comparison spends more of its funding on product development. The American investment in basic research has fueled many break-through developments. With total research and development spending being 2.5 times greater than China's (using purchasing power parity), America is clearly ascendant.[85]

The U.S. has the highest number of globally ranked universities with over 450,000 graduate students and research assistants in the science and technology fields.[86] America also has 75 universities ranked in the world's top 200 with more than 100 that conduct technology-based research.[87] China has, however, made great strides to improve their higher education system. China will soon graduate more Science, Technology, Engineering, Mathematics (STEM) doctors than any other country in the world, but their higher education system still has many systemic issues. Chinese Communist Party committees control state-owned universities which is limiting technical innovation.

The National Science Foundation Indicators Report also shows China has overtaken the U.S. in the number of science and engineering articles published, but all is not as it seems. The rapid growth in the number of papers China is publishing correlates with the increased number of PhDs China is graduating. However, analysis by the McKinsey Global Institute found that even though China produces the largest number of AI citations, the U.S. and its closest ally, the United Kingdom, publishes research that remains more influential. Also, McKinsey's analysis of Chinese open source reporting concludes that China trails behind that of the U.S. concerning fundamental research that advances AI.[88]

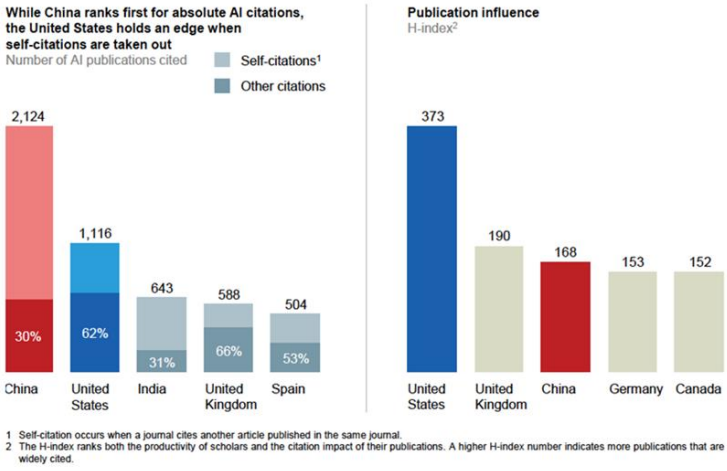


Figure A2. Although China produces a large number of widely cited AI-related papers, the US and UK remains far more influential. Credit: McKinsey Global Institute, 2015

Weaknesses

The U.S. does not currently have a national AI strategy or a national-level advocate for AI—this is a critical weakness. China is mounting an aggressive, multi-year, state-sponsored AI campaign to overtake the U.S. Although President Trump's 2017 *National Security Strategy* and the 2018 National Defense Strategy identify AI as an emerging technology that is critical to maintaining economic growth and security, the Trump administration has not yet translated the goals into specific AI-related actions. In October 2016, President Obama's Office of Science and Technology (OSTP) published *The National AI Research and Development Strategic Plan* which provided seven strategic recommendations. The strategy calls for: increased funding for AI research; development of safety, ethics, and trust policies to mitigate potential societal risks of AI; creating and sustaining a healthy AI workforce; and promoting collaboration between the government and the private sector. [89]

If the U.S. does not continue to develop and retain a highly trained AI workforce, it risks losing its competitive edge to China. AI experts are in short supply across the globe, resulting in

an intense competition to recruit experts with experience. The demand for experts will only increase as AI applications continue to be adopted by the commercial sector. China has taken steps to improve their university systems to allow its graduates to better compete against the U.S. and has an aggressive campaign to recruit non-Chinese foreign nationals. A 2015 National Science Foundation survey found that international students make up 81% of full-time graduate students in electrical engineering, 79% in computer science and 62% in mechanical engineering at American universities.[90] These graduate students possess the critical skills required to maintain our competitive edge. A National Foundation for American Policy October 2017 policy brief warns the Trump administration is considering eliminating the STEM Optional Practical Training provision that allows F-1 international students in STEM to work in the U.S. after graduation.[91] Preventing foreign-born talent from working in the U.S. after graduation could seriously impact our competitive advantage in AI.

The Defense Department also requires security-cleared AI experts with post-graduate degrees to support weapon systems, intelligence systems, and cybersecurity. However, the Department of Defense, Federal Funded Research and Development Centers (FFRDC), and traditional defense contractors are finding it hard to hire the research talent needed in this environment.[92] Compensation for recent masters and doctorate graduates with experience in AI can be as much as $300,000 to $500,000, prices which the public service is not willing to pay.[93] The Department of Defense has the potential to become overly dependent on non-traditional defense contractors for AI and robotics innovation, but these risks can only be mitigated if they are recognized and managed. A strong defense–commercial sector partnership with non-traditional defense contractors is essential to rapidly adapt commercial sector technologies to support national security missions however, challenges abound. These non-traditional firms typically have more foreign nationals and an American workforce that is not usually cleared to support national security projects. Furthermore, many commercial high-tech firms find it more profitable to forego pursuit of national defense contracts since defense work provides a lower return on investment compared to the commercial sector work. A new development is that some high-tech firms have philosophical issues with providing support to the Defense Department and intelligence community. Their employees do not want to accept work for military weapon systems or government surveillance system.

Opportunities

The U.S.' dominant position enables us to have an influential role in defining AI interface standards, ethical, trust and verification policies to ensure American industrial base and federal government equities are addressed. The U.S. also has many close allies with whom it currently collaborates to develop cyber defense and weapon system capabilities: the United Kingdom, Canada, and Israel have a deep pool of AI talent that the U.S. can continue to leverage to mitigate threats from China and Russia.

The National Security Telecommunications Advisory Committee, a body that provides advice to the President on cybersecurity, believes that AI and machine learning will have transformative implications for cybersecurity and cyberwarfare.[94] They call for White House leadership to promote enhanced government-industry-academic partnerships and for increased

funding for accelerated research and development, and adoption of near-term and long-term transformative cybersecurity technologies required to advance AI and autonomous systems.

Changes to the U.S. tax code enacted in 2017 reduced the corporate tax rate from 35% to 21% providing the commercial sector and defense contractors with a break that has the potential to re-direct additional resources to internal research and development.

Chinese companies have invested in sensitive AI-related American technology companies without following normal U.S. regulatory procedures.[95] China uses state-sponsored companies, or shell companies based outside of China, to acquire American technology companies to capture and transfer their intellectual property.[96] Consequently, Congress and the Trump Administration are working with industry to revise the federal statute that governs the Committee on Foreign Investment in the U.S. (CFIUS) to give it expanded authority to prevent China and other countries from acquiring American companies that possess such sensitive technology.

Threats

Three major threats could impact the U.S.' ability to maintain its competitive advantage as the world's leader in AI. First, based on current federal spending and tax plans the debt burden is estimated to grow to 100% of gross domestic product by 2020 with an annual deficit or nearly $1 trillion. Economic stability is essential to allow the private sector and the federal government to match the investments that China is making in AI. The U.S. must continue to have a strong economy with modest growth in gross domestic product and minimized economic recessions.

Secondly, regulations passed by the federal government, Congress and other world bodies may slow down the adoption of AI in the U.S. AI is still in its infancy. The technology is fraught with hype, fear, and distortions. A 2016 report from the White House found that AI enabled automation threatens millions of jobs.[97] In August 2017, a group of 116 founders of industry-leading robotics and AI companies from across globe wrote an open letter to the United Nations calling for the ban of autonomous lethal weapons.[98] The U.S. does not yet fully understand the ethical, legal, and societal implications of AI. Furthermore, additional research and policies are needed to ensure the safety and security of AI systems. As AI matures, American society will demand that the federal government and industry address these issues.

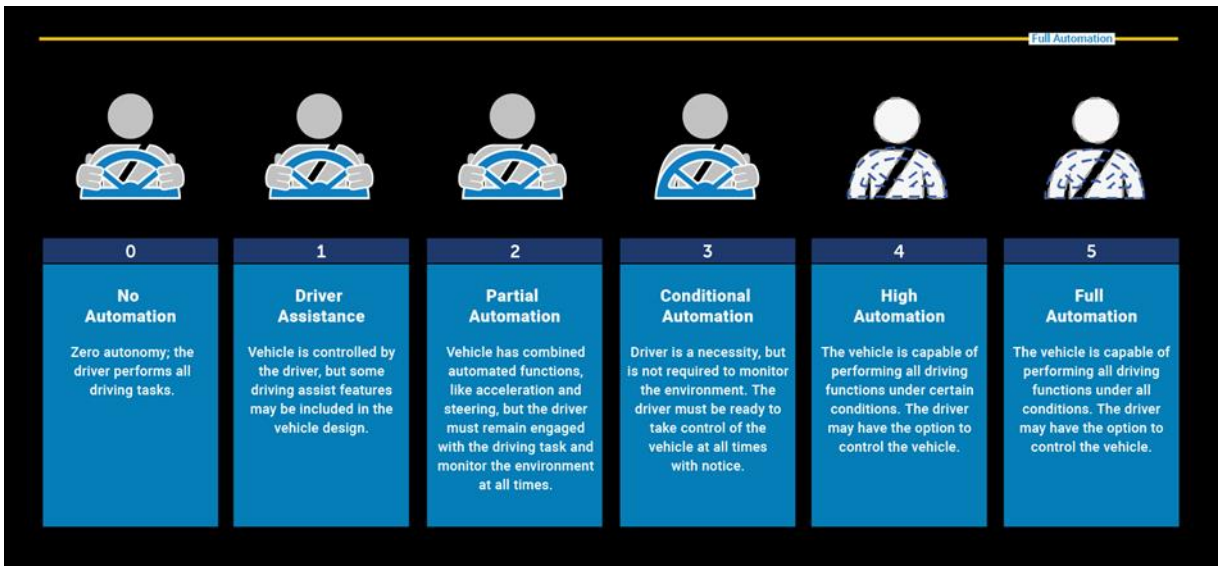
Thirdly, AI applications are vulnerable to cyber-attack. AI is reliant on computer processing and high and low bandwidth data communications. Although improving the nation's cybersecurity posture is a national priority, a February 2017 Defense Science Board Task Force on cyber deterrence found while the U.S. is making progress, it will take another decade before we are able to defend key critical infrastructures from cyber-attack.[99] The same is true for digital autonomous systems. High profile cyber-attacks by nation states, terrorists, or hacktivists could slow down the adoption of AI.

APPENDIX B - NOTEABLE MILESTONES IN ARTIFICIAL INTELLIGENCE DEVELOPMENT

1941	Isaac Asimov publishes his Three Laws of Robotics
1950	Alan Turing introduces Turing test
1950s	Neural Net concepts first developed
1950s-1960s	Neural Networks in vogue among computer scientists
1956	John McCarty holds Dartmouth College conference where term Artificial Intelligence is first coined
1958	Frank Rosenblatt prototype neural net for the Navy called the *Perceptron*
1965	Donald Michie holds one of the first annual AI conferences in Edinburgh
1974-early 1980s	Deep AI funding cuts referred to as the “AI Winter”
1980s	Breakthroughs in key neural net algorithms happen
1986	Geoffrey Hinton and colleagues write breakthrough paper addressing error correction in neural net
1987-1993	Deep AI funding cuts usher in the second AI Winter
1990s	Breakthroughs in key neural net algorithms happen
1990s	Sepp Hochreiter and Jurgen Schmidhumer pioneer a foundational natural language processing algorithm
mid-1990s	Neural nets fall out of favor for more effective machine-learning tools
1997	IBM Deep Blue computer beats Gary Kasparov
2005	Stanford University-led team wins DARPA Grand Challenge with “Stanley”
2006	First Women in Machine Learning Conference Held
2007	Stanford Professor, Fei-Fei Le, launches ImageNet initiative
2007	SRI spins off *Siri* Inc.
2009	ImageNet goes live
2009	Geoffrey Hinton inspires Microsoft to experiment with neural nets for speech recognition
late 2000s	NVIDIA’s Graphical Processing Units (GPU) recognized as 20-50x faster than conventional Central Processing Units (CPU)

2010	iPod designer Tony Fadell starts the Nest company
2010	Apple acquires *Siri*, Inc.
2011	Microsoft introduces deep learning into its commercial speech-recognition products
2011	IBM *Watson* beats two Jeopardy Champions using AI
2011	Apple introduces *Siri* as an integrated feature in its iPhone
2012	Andrew Ng and Jeff Dean of Google Brain Team publish results of the “Cat Experiment” that explored use of unsupervised AI learning
2012	Google introduces deep learning into its speech recognition products
2012	Two students of Geoffrey Hinton develop software that identifies objects in photos with twice the accuracy of the nearest competitor in the ImageNet contest
2014	Facebook researchers publish work on DeepFace, a program that uses neural nets to identify faces with 97% accuracy
2014	Release of Amazon Echo, featuring AI Alexa, to Prime members
2015	Deep learning entrant in ImageNet competition surpasses human performance
2015	AlphaGo, developed by Google DeepMind, defeats Fan in the Game of Go Champion Hui five games to zero
2016	Google reveals self-developed tensor chips it uses in deep learning-developed application
2016	AlphaGo defeats world Go champion, Lee Sedol, in 4 of 5 matches
2017	AlphaGo wins 60-0 against world champion Ke Jie
2017	Computer program *Libratus* defeats four of the world’s best Texas Hold-em players

APPENDIX C - SOCIETY OF AUTOMOTIVE ENGINEERS' LEVELS OF VEHICLE AUTOMATION



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