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Emerging Science and Technology Trends: 2016–2045

A Synthesis of Leading Forecasts

Office of the Deputy Assistant Secretary of the Army (Research & Technology)

DISCLAIMER

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EXECUTIVE SUMMARY

This is the third annual report on emerging trends in science and technology (S&T) published by the Deputy Assistant Secretary of the Army for Research and Technology (DASA R&T). As in prior years, the report has two primary objectives. First, it is intended to inform leaders across the U.S. Army and stakeholders in the joint, interagency, and international community about S&T trends that are likely to influence the future operating environment and shape warfighting capabilities over the next 30 years. Second, it is intended to spark strategic dialogue around the kind of S&T investments the Army should make to ensure that our Soldiers maintain overmatch in future operations.

This 2016 version of the S&T Strategic Trends report synthesizes 32 S&T forecasts that have been published over the past five years by government agencies in the U.S. and abroad, industry leaders, international institutions, and think tanks. The objective was to identify trends that are most likely to generate revolutionary or disruptive change of interest to the Army over the next 30 years. By consolidating multiple trend analyses into a single reference document, this report aims to provide a ready reference for Army leadership as it considers the important role S&T will play in shaping the future of our Army.

Analysis of the source documents produced 690 individual trends related to science and technology, as well as trends related to broader contextual factors that will shape the evolution of S&T over the coming decades. From this data set, 24 emerging science and technology trends were identified:

- *Robotics and autonomous systems*
- *Additive manufacturing*
- *Analytics*
- *Human augmentation*
- *Mobile and cloud computing*
- *Medical advances*
- *Cyber*
- *Energy*
- *Smart cities*
- *Internet of things*
- *Food and water technology*
- *Quantum computing*
- *Social empowerment*
- *Advanced digital*
- *Blended reality*
- *Technology for climate change*
- *Advanced materials*
- *Novel weaponry*
- *Space*
- *Synthetic biology*
- *Changing nature of work*
- *Privacy*
- *Education*
- *Transportation and logistics*

In addition to these emerging S&T trends, this report discusses six broad contextual forces that are likely to shape the evolution of science and technology over the next 30 years: urbanization, climate change, resource constraints, shifting demographics, the globalization of innovation, and the rise of a global middle class.

As with previous editions of the S&T Strategic Trends report, a set of "trend cards" are included in this report. These cards provide additional detail on the S&T trends, including a synopsis of each trend, along with summaries of enabling S&T domains, recent developments that signal how each trend might evolve, and a high-level consideration of the impacts each trend might have on society, politics, economics, the environment, and defense. These trend cards provide a convenient reference for trends that have the most potential for influencing Army capabilities and the future operating environment.

Science and technology are part of a system of driving forces that will change many aspects of the world over the next 30 years. While it is impossible to accurately predict the future in detail, the trends discussed in this report will influence the course of global change with ramifications for the U.S. Army. The intent behind the analysis presented here is to inform Army leadership about where the future might be headed, and by doing so, support strategic thinking about how best to prepare the force for the road ahead.

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BACKGROUND

This is the third annual report on emerging trends in science and technology (S&T) published by the Deputy Assistant Secretary of the Army for Research and Technology (DASA R&T). As in prior years, the report has two primary objectives. First, it is intended to inform leaders across the U.S. Army and stakeholders in the joint, interagency, and international community about S&T trends that are likely to influence the future operating environment and shape Army capabilities over the next 30 years. Second, it is intended to spark strategic dialogue around the kind of S&T investments the Army should make to ensure that our Soldiers maintain overmatch in future operations. This report is part of the DASA R&T's broader Technology Wargaming program, which seeks to provide strategic foresight research and analysis in support of both S&T investment planning and Unified Quest, the Army's annual future study program sponsored by the Chief of Staff and conducted by the Army Capabilities Integration Center (ARCIC).

We stand on the cusp of technological revolutions on multiple fronts, in fields as diverse as robotics and synthetic biology. Technology has been central to the American way of war throughout the nation's history,[1] and it is safe to assume that scientific and technological advancements will remain an important foundation for U.S. Army capabilities over the next 30 years and beyond. At the same time, the global economic and political landscape is undergoing the most profound realignment since the fall of the Soviet Union. The United States military has long relied on an overwhelming advantage in research, development, and innovation that is unlikely to persist much longer. As China, Russia, and other nations modernize their militaries through investments in science and technology, it will become essential for the U.S. Army to make the most effective use of S&T investments to stay ahead of emerging threats.

Effective investment strategies start with an understanding of emerging trends. Therefore, the aim of this edition of the S&T Strategic Trends report is to identify the major trends in science and technology that are likely to influence Army capabilities and the future operating environment over the next 30 years. The approach toward identifying these trends involved a comprehensive review and synthesis of open source forecasts published by government agencies in the U.S. and abroad, industry analysts, think tanks, and academic organizations. These institutions are also grappling with the influence of S&T on social, political, economic, environmental, and defense-related issues, and an analysis of the documents they produce reveals a number of common themes. Rather than duplicating the numerous S&T-related forecasts conducted by the U.S. National Intelligence Council, U.K. Ministry of Defense, the McKinsey Global Institute, and other major organizations, this report seeks to leverage their collective insights to identify trends that will impact the U.S. Army.

In that vein, a comprehensive literature search was conducted to identify trend forecasts published by foreign and domestic government agencies, industry analysts, academic organizations, and think tanks. A total of 32 reports were selected based on the following criteria:

- *All of the reports had to be the product of rigorous and well-documented research conducted by reputable organizations with a track record of producing high-quality trend analysis.*
- *All of the reports had to have been published within the past 5 years.*
- *All of the reports had to address science and technology trends that could influence Army operations and the future operating environment over the next 30 years.*
- *All of the reports had to address a wide range of science and technology trends. Narrow forecasts related to highly specific industries or technology domains were not included in this analysis.*

Appendix A provides a complete bibliography of the sources that were used to conduct this synthesis of emerging science and technology trends. Overall, 9 sources were carried over from the 2015 Emerging Trends report, while 23 new sources were added. A content analysis of these documents (described in Appendix B) identified 690 specific trends related to science and technology as well as societal, economic, environmental, and political trends that are likely to shape the context in which scientific and technological developments will occur. Further analysis of the trend data revealed 24 common science and technology "mega-trends" that have the potential to shape future Army operations and the future operating environment. The analysis also identified six cross-cutting contextual trends that will influence how science and technology could evolve. Details on the analysis methodology are presented in Appendix B.

The remainder of this report is divided into two primary sections. The first section reviews the science and technology trends that were identified through the synthesis of open source forecasts. As with the 2015 Trends report, a set of "trend cards" has been prepared that summarizes each of these trends. The cards, which are appended to the end of this report, provide a brief synopsis of each trend, review key scientific and technical enablers of the trend, highlight recent developments that signal how each trend might evolve over the coming decades, and review some of the impacts that each trend might have on society, politics, the economy, the environment, and national defense. The second section of the report reviews six contextual trends that appeared as common themes in many of the source documents. These trends speak to broader undercurrents that will shape the nexus among S&T, sociopolitical change, and national security through 2045.

1. *Mahnken, T.G. (2010). Technology and the American Way of War Since 1945. NY: Colum bia University Press.*

An analysis of the source reports identified 20 core S&T trends that will influence the world over the next 30 years:

Robotics and Autonomous Systems

By 2045, robots and autonomous systems are likely to be commonplace. Autonomous vehicles will make transportation safer and more efficient, while possibly fueling the rise of the sharing economy. Robots will care for the elderly, deliver groceries, harvest crops, maintain public infrastructure, and provide many other services that touch everyday life. Intelligent software agents, or "bots", will extract insights from terabytes of data, automate business processes, and step into customer service, teaching, and other roles traditionally seen as "people-centric". However, the rise of autonomous systems could displace hundreds of millions of labor and service workers, creating economic instability and the risk of social unrest. Networked autonomous systems will also become an attractive target for adversaries and a new priority for cyberdefense. The use of robots in military operations will expand as robotic systems gain mobility, dexterity, and intelligence, making robots effective partners on future battlefields. At the same time, adversaries will use robots and autonomous systems in ways that challenge us ethically and tactically.

Additive Manufacturing

Additive manufacturing (3D printing) has been used in industry for over 30 years, mostly as a tool for limited-run prototyping. However, there has been remarkable innovation in 3D printing technology over the past ten years. Prices for 3D printers are falling, and the availability of open source tools and 3D models from online marketplaces like Thingiverse has fostered the growth of a vibrant community of hobbyist "makers" who are pushing the boundaries of what this technology can do. By 2040, 3D printers will be able to print objects that incorporate multiple materials, electronics, batteries, and other components. People will be able to print tools, electronics, replacement parts, medical devices, and other products on demand, customized to their wants and needs. Military logistics will likely become streamlined, as equipment and supplies will be printed directly at their point of use. Objects will become information, and digital piracy will replace shoplifting. Terrorists and criminal organizations will print weapons, sensors, and other equipment using raw materials that will be almost impossible to track.

Analytics

In 2015, the world generated 4.4 zetabytes of data (4.4 trillion gigabytes), and this figure is expected to roughly double every two years. This flood of data holds deep insights into consumer behavior, public health, climate change, and a range of other economic, social, and political challenges. However, while "Big Data" has become a buzzword, less than 10% of data generated each year ever gets analyzed. Over the next 30 years our ability to make better use of massive, dynamic data sets will improve. Automated bots will crawl unstructured data, identifying relationships that are visualized in immersive virtual datascapes. Analytics will spread beyond the enterprise, as people gain the ability to apply big data to their personal lives. Citizens will have the ability to use data to hold governments and other major institutions accountable, leading to tensions over data access. The rise of hyper-personalized marketing, government surveillance of citizens' data trails, and high profile cases of data loss could fuel growing concerns over data ownership. Potential adversaries will use data that is stolen, purchased off dark networks, or accessed freely from open sources to compromise security and challenge U.S. defense capabilities.

Human Augmentation

Over the next 30 years, technology will allow us to transcend biological limits on human potential. Wearable devices connected through the Internet of Things will deliver context-sensitive information overlaid directly onto our senses. Exoskeletons and brain-interfaced prosthetics will make us stronger and restore mobility to the elderly and infirm. Sensors and computers embedded in contact lenses and permanent implants will let us hear whispers behind walls, give us natural night vision, and allow us to immerse ourselves in virtual and augmented realities. Nootropic drugs will expand our cognitive abilities and transform work and education. Of course, augmentation technology will come at a price, and those who cannot afford to upgrade their "human chassis" might find themselves unable to compete in the augmented economy. Networked augmentations will also be an appealing target for hackers looking to control over our very minds and bodies. While the U.S. Army will benefit from augmenting its Soldiers, the force will face adversaries who are similarly enhanced, and an augmentation arms race could evolve.

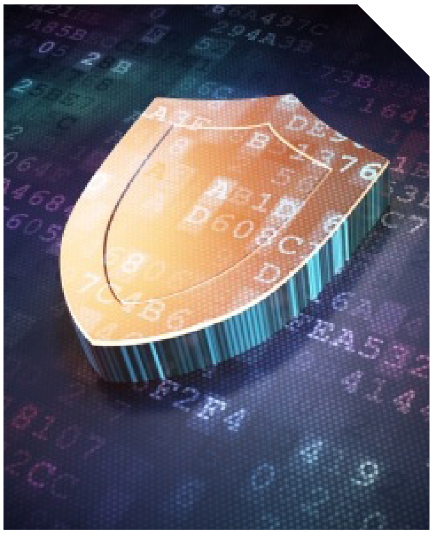
Mobile & Cloud Computing

Mobile and cloud computing are transforming the way people interact with data. In the United States, an estimated 30 percent of Web browsing and 40 percent of social media use are currently done on mobile devices. By 2030, 75% of the world's population will have mobile connectivity and 60% should have broadband access. Mobile devices are becoming more powerful and feature-rich, with a growing variety of embedded sensors that measure weather, location, ambient light and sound, and biometrics. Working in tandem with mobile data access, cloud computing provides access to almost unlimited computational power that scales seamlessly without requiring massive investments in IT infrastructure. Over the next 30 years, cloud-based mobile computing has the potential to transform everything from health care to education. Cell phones will monitor vital signs and communicate directly with diagnostic applications, people will use online educational portals from mobile devices to learn new skills, and apps will allow farmers in developing nations to connect to real-time weather data and tools for optimizing their harvests. At the same time, mobile and cloud computing will put significant pressure on network security, reliability, and bandwidth, and both consumers and enterprises will have to grow more comfortable with relinquishing their data to the cloud.

Medical Advances

Over the next 30 years, medicine will be transformed by multiple technological breakthroughs. Genomics will give rise to personalized medicine, with treatments for cancer, cardiovascular disease, Alzheimer's, and other diseases tailored to individual genetics. Artificial organs will be grown for transplantation from DNA samples, eliminating wait times for life-saving transplants and the risk of organ rejection. Prosthetics will be wired directly into the nervous system and will incorporate biologically based sensors that provide a near-normal sense of touch. Robotic first responders and tissue preservation techniques such as controlled hypothermia will revolutionize trauma care and greatly extend the "golden hour" for wounded Soldiers. As scientists unlock the keys to aging, people will live longer and stay healthy and active well into what today we consider "old age". At the same time, the cost of advanced medical care will stress many national health care systems and trigger rising inequality in access to life-saving treatments. The coming medical revolution will also enable people to remain healthy and productive for decades longer, amplifying competition for jobs between older and younger workers and creating additional strain on social safety nets. Drug resistant bacteria will become an urgent problem in many parts of the world.

Cyber



Cyberdefense is hardly a new trend—warnings about a "cyber Pearl Harbor" were made as early as 1991. However, over the next 30 years the rise of the internet of things and growing interdependence among connected aspects of everyday life will bring cybersecurity to the forefront. While the number and scope of cyberattacks is increasing, most have been targeted against individual consumers or corporations and the damage from individual attacks, while extensive, has been easily contained. As cars, home appliances, power plants, streetlights, and millions of other objects become networked, the potential for a truly devastating cyberattack will grow. Nations, corporations, and individuals will be challenged to secure their data from ever more insidious attacks—many of which may go undetected for years. The worst-case scenario envisions a form of "cybergeddon", in which the immense economic and social power of the Internet collapses under the weight of relentless cyberattacks.

Energy

Over the next 30 years the global demand for energy is projected to grow by 35%. The development of methods like fracking and directional drilling have opened vast new reserves of oil and natural gas. These technologies have up-ended global oil markets and turned the United States into one of the world's largest fossil fuel producers. At the same time, renewable energy sources such as solar and wind are approaching cost-parity with fossil fuels. In the past two decades, the cost of power produced by solar cells has dropped from nearly $8 per watt of capacity to less than one-tenth of that amount. Nuclear, while still the subject of intense public debate, is continuing to grow, with new reactor designed promising greater safety and less radioactive waste. While adoption of cleaner energy sources would help combat global climate change, new frictions will emerge over access to rare materials used in batteries, solar cells, and other linchpins of the energy revolution. The fading of fossil fuels also carries significant risk of economic and social destabilization across the Middle East and North Africa, presenting new security challenges for the United States and its allies.

Smart Cities

By 2045, 65-70% of the world's population—approximately 6.4 billion people—will live in cities. As urban populations swell, the number of megacities with 10 million inhabitants or more will grow, from 28 in 2016 to 41 by 2030. Mass migration to cities will put significant pressure on urban transportation systems, food and water supplies, power and energy infrastructure, sanitation, and public safety. Information and communications (ICT) technology will support the growth of "smart cities" that use data and automation to make urban centers more efficient and sustainable. Distributed sensor systems will monitor water and power usage and automatically balance distribution via smart grids. Networked traffic systems and autonomous transportation options will ease gridlock. New materials and design techniques will be used to build smart buildings that maximize the efficiency of heating, cooling, and lighting. Rooftop solar panels, micro-wind turbines, thermal power, and other renewable energy sources will provide clean, distributed power generation. At the same time, cities that cannot afford to invest in these technologies (or that lack the political will to do so) could turn into congested, dirty, and dangerous flashpoints for instability and conflict

Internet of Things

According to conservative estimates, there will be over 100 billion devices connected to the Internet by 2045. This will include mobile and wearable devices, appliances, medical devices, industrial sensors, security cameras, cars, clothing, and other technologies. All of these devices will produce and share vast amounts of information that will revolutionize how we work and live. People will use information generated through the Internet of Things (IoT) to make smarter decisions and gain deeper insight into their own lives and the world around them. At the same time, web-connected devices will also automate many monitoring, management, and repair tasks that currently require human labor. The intersection of the IoT, analytics, and artificial intelligence will create a global network of smart machines that conduct an enormous amount of critical business with no human intervention. While the IoT will improve many aspects of economic efficiency, public safety, and personal productivity it will also exacerbate concerns over cybersecurity and privacy. Criminal organizations, terrorists, and adversarial nation states will use the IoT as a new vector for attacking the United States and its allies. The immense amount of data generated through web-connected devices will also enable governments to conduct mass surveillance on populations, leading to ongoing tensions between digital freedom and security.

Food and Water Technology

Over the next 30 years, inadequate access to food and fresh water will become a crisis point in many parts of the world. Roughly 25% of current farmland is already degraded from overfarming, drought, and air/water pollution. Under optimistic forecasts, prices for staple grains could rise by 30% over the coming decades—increases of 100% are not out of the question if climate change, demand patterns, and failed resource management continue on current trajectories. By 2045, 3.9 billion people—over 40% of the world's population—could face water stress. Technology offers many potential solutions to food and water crises. Desalination, micro-irrigation, water reclamation, rainwater harvesting, and other technologies could relieve pressure on fresh water supplies. Genetically modified crops and automation could improve crop yields and allow farmers to produce more nutrition from less land. Food and water, long taken for granted in the developed world, will become a major focus for innovation, and could become a major flashpoint for conflict.

Quantum Computing

Quantum computing uses properties of subatomic particles like superposition and entanglement to encode and manipulate data. While the technology has been discussed as a theoretical possibility for decades, recent research efforts across academia, industry, and government labs are beginning to demonstrate quantum systems that might have practical applications in the next 5-15 years. Quantum computing could be a linchpin technology that revolutionizes multiple other technical domains such as climate modeling, pharmaceutical research, and materials science. However, most of the interest in quantum computing is related to how it would transform cryptography. A quantum computer could crack all current encryption methods, and quantum cryptography could provide the first truly unbreakable encoding technology. Recent research has begun to overcome many of the technical problems that have limited the development of practical quantum computers. While real-world applications of quantum computing might not be seen until the mid-2040s, an influx of investment by governments and industry signals that quantum computing might be approaching a tipping point.

Social Empowerment

Approximately 65% of American adults now use social media—up from 7% in 2005.[2] Social media has undoubtedly changed the way people connect online, but over the next 30 years, social technologies will become an engine for empowering individuals to shape their own micro-cultures. Many traditional power structures will be overturned as people form Internet-based communities defined by technologically-mediated social contracts. Governments will find it increasingly difficult to control the political narrative as people share eyewitness accounts of corruption and oppression directly, without the filter of mass media. While corporations will learn new techniques for engaging with consumers through social channels, those same consumers will use social platforms to cut through advertising noise and hold businesses accountable for their products and actions. Crowdsourcing and content streaming will further democratize content creation and blur the lines between media creators and consumers. Bitcoin and other cryptocurrencies could lead to definitions of currency and trade based on social consensus rather than government control. For the U.S. Army, social empowerment will radically change how young people view national service. For example, people who define themselves first and foremost as members of online communities may be less attracted by appeals to patriotism and public service. Social media sharing will also make it more challenging for the Army to win the battle of narratives in future conflicts.

Advanced Digital

Computers and other digital devices have transformed life so completely over the past 60 years that it is almost impossible to remember that these technologies are relatively new. The first personal computers weren't sold until 1975, and were only available as kits that customers had to assemble and program on their own. However, just 40 years later, 68% of Americans own smartphones that have more processing power than NASA did when it sent astronauts the moon in 1969.[3] The next 30 years will likely continue the trajectory toward more computing power and wider availability of digital resources. Mobile and cloud computing will provide almost unlimited memory and processing speed. Virtualization and software-defined systems will allow governments and business to rapidly adapt IT infrastructure without costly and wasteful hardware upgrades. Digital will become integrated into an even wider array of everyday objects, from clothing to building materials. At the same time, technologies are emerging that will transform how we interact with our devices. Voice interfaces are already commonplace in smartphones, and will continue to improve. Gestural interfaces will allow us to communicate with computers through nonverbal behavior. Ultimately, brain-computer interfaces will allow us to control devices through thought, making digital systems as natural an extension of our bodies as our own limbs. All of these developments will open new opportunities and new challenges for the Army. For example, embedded digital systems will connect Soldiers to each other and to autonomous software agents that will support sustainment, fire coordination, and intelligence analysis. On the other hand, the proliferation of advanced computing capabilities will increase the risk of crippling cyberattacks.

Blended Reality

Virtual and augmented reality (VR and AR) have been generating a lot of enthusiasm within the consumer electronics industry. Facebook will be entering the VR headset market this year with a system developed by Oculus VR, which the social networking giant purchased in 2014. Other major electronics companies, including Samsung, Sony, and HTC are all releasing virtual reality products this year, signaling a major breakout of VR as a mainstream entertainment technology. Applications are emerging outside of entertainment. For example, the home improvement chain Lowes is developing the Holoroom—a 3D augmented reality room that allows shoppers to design a living area and then walk into a virtual model of the space to get a better feel for how it will look. While VR and AR have a history of overinflated expectations—VR was expected to revolutionize media in the 1990s—the combination of ultra high-resolution displays, low-cost position and location tracking, and high definition video content has laid a solid foundation for "blended reality" technologies that merge the real world with digital information. Over the next 30 years these technologies should become more prevalent. AR displays will deliver real-time, context-aware data overlays, and VR will enable deeply immersive experiences integrating sight, sound, smell, and touch. For the U.S. Army, VR and AR have applications from training to combat operations. For example, maintenance personnel will be able to visualize diagnostic data and repair routines through AR overlays that project information directly onto physical equipment. On the other hand, it will be important to design VR and AR systems that do not exacerbate information overload or create distractions that put situation awareness at risk.

2. Andrew Perrin. "Social Networking Usage: 2005-2015." Pew Research Center. October 2015. Available at: http://www.pewinternet.org/2015/10/08/2015/Social-Networking-Usage-2005-2015/.

3. Kaku, M. (2012). Physics of the Future: How Science Will Shape Human Destiny and Our Daily Lives by the Year 2100. NY: Doubleday.

Technology for Climate Change

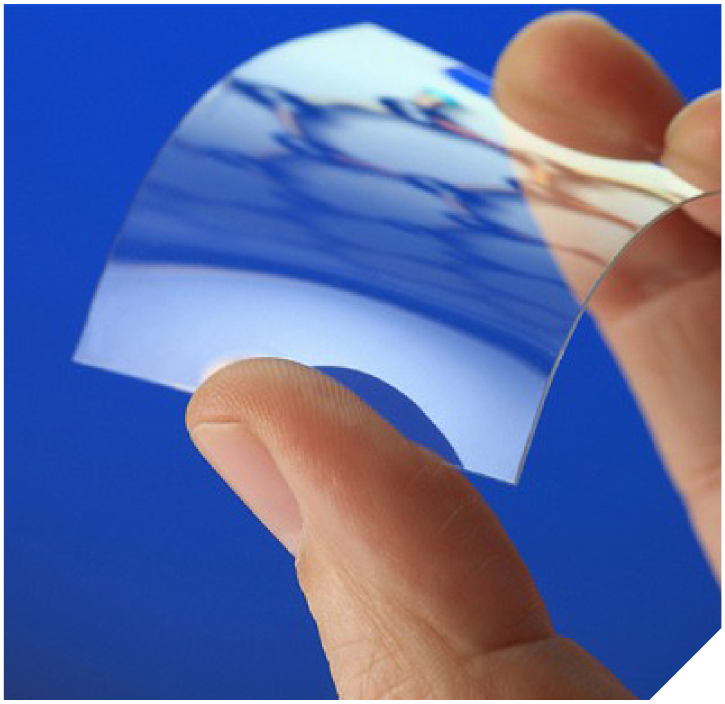
Current data points to a rise in global surface temperatures of 2.5 to 5.4 degrees Fahrenheit by 2050. Even if dramatic steps were taken today to reduce greenhouse gas emissions, climate inertia guarantees that some warming will be inevitable.[4] As a result, sea levels are likely to rise, threatening coastal cities; crop yields could decline, leading to famine in parts of the developing world; drought could threaten millions of people with a lack of fresh water, and flooding could cause billions of dollars in damage to homes, businesses, and public infrastructure. Over the next 30 years, these risks will drive investment in technological solutions for mitigating the potential effects of climate change. In the near-term, climate change technologies will include systems for mapping flood hazards and genetically-modified crops engineered for drought resistance. Over the longer term, more ambitious technologies may emerge, such as carbon sequestration methods that can pull greenhouse gases like carbon dioxide and methane out of the atmosphere and store them safely underground. If climate change appears to be following worse case scenarios of 4-5 degrees of warming or more, there could be truly destabilizing effects on the Earth's climate that are impossible to mitigate. Under those conditions, serious efforts at geoengineering might become the only solution to avoiding catastrophic climate change. For example, scientists have estimated that seeding the atmosphere with sulphur or aluminum oxide particles to reduce the amount of solar radiation hitting the Earth. These interventions are still highly theoretical and could be extremely risky.

Advanced Materials

Materials science has led to impressive advances over the past ten years, such as smart materials that are self-healing and self-cleaning; memory metals that can return to their original shapes; piezoelectric ceramics that can be used to harvest energy from pressure; and nanomaterials that have remarkable structural and electrical properties. Nanomaterials in particular have tremendous potential across a wide range of applications. At nanoscale (less than 100 nanometers), ordinary materials such as carbon take on unique properties. For example, graphene, a lattice formed from individual carbon atoms, is 100 times stronger than steel, conducts heat and electricity efficiently, and is nearly transparent. Nanomaterials have applications in super-slick coatings for engines and other machines, stronger composites for aircraft and cars, lightweight body armor, and high efficiency photovoltaics. Beyond industrial applications, pharmaceutical companies are developing therapeutic nanoparticles that could one day deliver targeted drug treatments for cancer that greatly reduce side effects while enhancing treatment outcomes. Over the next 30 years, nanomaterials and other novel materials such as metallic foams and ceramic composites will be found in clothing, building materials, vehicles, roads and bridges, and countless other objects. The Army will be able to leverage advanced materials to produce lighter, stronger body armor, more efficient vehicles and shelters, and more robust batteries and renewable energy systems.

Novel Weaponry

Over the next 30 years, a number of novel weapon technologies could proliferate across future battlefields. In addition to technologies that are currently under development, such as nonlethal weapons and directed energy systems, a number of nations are investing in anti-access area denial (A2AD) technologies that could significantly impact the United States Army's ability to maneuver freely through future operating environments. Emerging A2AD technologies include anti-ship ballistic missiles; precision guided anti-vehicle and anti-personnel munitions; counter rocket, artillery, and mortar (CRAM) systems, anti-satellite weapons; and electromagnetic pulse (EMP) systems. Some of these technologies, such as precision-guided munitions, will reflect innovation based on existing technologies. For example, China is developing advanced anti-ship ballistic missiles that have the potential to destroy aircraft carriers. Other technologies will reflect entirely new concepts, such as the self-guided bullet demonstrated by DARPA in 2015 as part of its Extreme Accuracy Tasked Ordnance (EXACTO) program. As China, Russia, and other nations make larger investments in military modernization the U.S. is likely to face adversaries with capabilities that approach, and in certain cases possibly exceed, our own.



4. IPCC, 2014: Climate Change 2014: Synthesis Report. Available from http://www.ipcc.ch/report/ar5/syr/.

Space

The space industry has entered a period of innovation and progress not seen since the space race of the 1960s. New technologies such as robotics, advanced propulsion systems, lightweight materials, additive manufacturing, and miniaturization are dramatically reducing the cost of putting people and material into space and opening up new possibilities for space exploration. New entrants to the space market, including SpaceX, Arianespace, and Blue Origin, are disrupting the stagnant commercial launch sector and driving innovations such as re-usable launch vehicles. Over the next 30 years, research and development will enable humans to return to the Moon, and could lead to more dramatic exploration, including human exploration of Mars and the start of entirely new space-based industries such as asteroid mining. While the exploration—and potential colonization—of space has long captured our imaginations, a growing dependence on space-based infrastructure could lead to new frictions here on Earth. As more nations come to rely on space-based assets the control of space could become a significant flash point. The militarization of space is not out of the question, and anti-satellite warfare could have profound effects on the U.S. Army, which relies heavily on satellites for secure global communications, intelligence gathering, and coordinating joint maneuver.

Synthetic Biology

Humans have manipulated the genetic code of plants and animals through selective breeding and hybridization for millennia—well before Mendel identified the basic laws of heredity or the Avery-MacLeod-McCarty experiment identified DNA as the genetic material. However, as our understanding of genetics has grown it is becoming possible to engineer custom organisms by building new sequences of DNA from scratch. Genetically-modified crops represent the vanguard of this technology, but we are on the cusp of a broader revolution that will turn life itself into information that can be written and rewritten much like computer code. Scientists are already engineering algae that can secrete biofuels and using DNA to encode thousands of gigabytes of data. Over the next 30 years, synthetic biology will give rise to engineered organisms that can detect toxins, create biofuels from industrial waste, and deliver medicine through symbiosis with human hosts. At the same time, synthetic biology represents profound risks, including engineered biological weapons and invasive synthetic organisms that could destroy natural ecosystems.

Four other S&T trends appeared in the source documents, but did not occur often enough to provide sufficient data for further analysis. Nonetheless, these technologies could have an impact on future Army capabilities, and are worth monitoring over the coming years:

Changing Nature of Work

Technology is transforming the relationship between individuals and their work. Freelancing is on the rise, fueled by access to web-enabled marketplaces and collaboration tools. Entrepreneurs are achieving rapid innovation using technologies like 3D printing and application program interfaces (APIs). Crowdfunding platforms like Kickstarter are changing the way products are developed by directly connecting "makers" with consumers. Over the next 30 years, these trends will redefine work. For some, declining barriers to entrepreneurship will create new opportunities. For others, competition in the "gig economy" will mean lower wages, lack of benefits, and economic insecurity.

Education

Technology is changing education. Online courses are now offered by colleges and universities; adaptive digital tutors are offering a new route for delivering instructional materials; and schools are routinely integrating tablet computers and other technologies into classrooms. The impact of emerging technologies on education could become an important source of innovation for Army training.

Privacy

A recent survey by the Pew Research Center found that 50% of Americans are concerned about the information available about them online—an increase of 51% since 2009. These numbers mirror global trends and point to growing concerns about privacy. In 2045, a market for personal privacy protection might emerge, including "off the grid" spaces where people can live, vacation, or congregate away from networked sensors. Technologies for protecting and "healing" online reputations could become more important as one's online behavior comes to have a more significant effect on real-world relationships and employment.

Transportation and Logistics

Autonomous vehicles and machine intelligence could revolutionize mass transport and logistics over the next 30 years. Autonomous transportation technologies could improve the efficiency of moving people and products within and between cities. Semi- or fully autonomous commercial airplanes, buses, and cabs could offer a safer way for people to travel while reducing congestion and pollution.

Emerging trends in S&T over the next 30 years will play out against a background of ongoing sociopolitical, economic, and environmental change. Over the coming decides, six key trends are likely to shape the nexus between sociopolitical change, technology, and security:

- *Urbanization*
- *Climate change*
- *Resource constraints*
- *Shifting demographics*
- *Globalization of innovation*
- *Rise of a global middle class*

Urbanization

By 2045, approximately 70% of the world's population will live in urban areas.[5] The majority of this growth is likely to occur in the developing world, particularly in Asia, as economic growth in China and India draw more residents to job opportunities near cities. The trend towards urbanization will expand the number of megacities—cities with more than 10 million residents—from 28 in 2015 to 41 by 2030.[6] If urbanization is managed successfully, hundreds of millions of people could be raised out of poverty by strong economic growth.[7] On the other hand, mismanaged growth could lead to cities that cannot provide enough fresh water, food, electricity, transportation access, and sanitation to sustain a healthy, productive population. Rapid migration to cities and increasing urban population densities could also exacerbate ethnic or religious tensions, particularly in cities that cannot provide sufficient resources to keep people safe and employed.

From a technology perspective, urbanization will encourage innovation on multiple fronts. Successful cities will develop innovative transportation systems that move people and goods efficiently without contributing to smog and other forms of pollution. Technological developments will include autonomous vehicles and mass transit systems that can be retrofitted to existing urban footprints. The need to provide food and fresh water to millions of urban residents will drive innovations such as vertical farming and water harvesting (e.g., graywater recycling). Cities will also drive innovation in information and communications technology. Urban centers will become central hubs for the Internet of Things, as millions of sensors form an information network the monitors traffic, air and water quality, power distribution, public safety, and numerous other facets of urban life. Many cities in the developing world will leap-frog traditional landline telecommunications and drive innovation in wireless and mobile communication. Robots might take over many roles currently held by human workers, such as sanitation.

Climate Change

By 2050, the average global surface temperature is forecast to rise by 2.5 to 5.4 degrees Fahrenheit.[8] Sea levels could rise up to five feet by the end of the century,[9] leading to increased flooding. Many coastal areas will become inundated with water, transforming coastlines around the world and adversely affecting millions of people living in coastal cities. Temperature change will also affect global weather patterns, leading to more frequent and more severe weather events in many parts of the world. Desertification will accelerate, leading to a decline in agricultural output. Agriculture in equatorial regions will be particularly affected, potentially causing food shortages across North Africa and the Middle East. Oceans, which absorb a large amount of atmospheric carbon dioxide, will experience increased acidification of up to 70% by 2050.[10] Acidification will cause potentially devastating ripple effects throughout the oceanic ecosystem, causing a decline in global populations of fish and other aquatic food stocks and increasing food stress in many regions of the world. At the same time, melting of polar ice will open vast new regions to exploration for energy and minerals. The Arctic is already becoming a focus of strategic maneuvering for the U.S., Russia, and Europe, and expanded access to polar resources could trigger interstate conflicts.[11]

Most experts agree that we are unlikely to entirely avoid the negative effects of climate change, even if radical action was taken today to reduce greenhouse gas emissions. Therefore, science and technology will likely play an important role in climate change adaptation. For example, analytics could be used to predict flooding hazards based on near-term meteorological data and long-term climate modeling. This would enable proactive responses by government planners and emergency services that mitigate threats to residents, buildings, and infrastructure. Agricultural technologies such as vertical farming could enable cities to meet food demand locally through farming methods that are more resilient to drought and other climate influences. And while a certain amount of warming is already locked into the global climate, clean energy technologies could mitigate the severity of future warming by reducing greenhouse gas emissions from burning fossil fuels.

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Resource Constraints

Over the next 30 years, global demand for food, water, energy, and material resources is likely to continue to increase dramatically. Global fresh water demand is projected to grow by 55% by 2045,[12] and unless steps are taken to mitigate water shortages, around 3.9 billion people—over 40% of the world's population—could experience water stress. Food supplies will come under pressure from population growth and declines in agricultural output due to climate change and mismanagement of arable land (some estimates indicate that up to 25% of farmland is already degraded due to overuse of chemical fertilizers and poor crop management practices).[13] While China and other industrialized nations are beginning to transition to renewable energy sources, global energy demand is expected to double by 2045, with supply continuing to undershoot demand.[14] Global reserves of materials such as copper and lithium, which are essential to the digital economy, are falling as demand increases. In 2030 it is predicted that 83 billion tons of minerals, metals and biomass will be extracted from the earth: 55 percent more than in 2010.[15] Countries that control large resource reserves are likely to gain immense control over the global economy. For example, China currently supplies 97% of global demand for rare earth metals. The Chinese government has already tightened rare earth exports, driving up prices for electronic components and boosting its own domestic electronics industry.

Resource constraints will be a powerful driver of global research and technology development. Water harvesting and recycling technologies, such as efficient desalination and water vapor farming, will reduce water stress. Agricultural output will benefit from new advances in transgenic crops, micro-irrigation, and autonomous systems. New manufacturing methods such as 3D and 4D printing will reduce waste and make use of recycled materials. Further afield, it is possible that by 2045 advances in space technologies could open the door to asteroid mining and a potentially enormous new source of raw materials. We are already seeing early signs of an emerging off-planet mining industry: in 2015, the Washington-based space mining company Planetary Resources launched the first in a series of probes from the International Space Station that are designed to scout asteroids in near-Earth space and the asteroid belt for water and precious metals.[16]

Shifting Demographics

The global population will reach 9.5 billion by 2045[17]—a 28% increase over the current world population of 7.4 billion. Population growth will be driven by a decline in deaths from infectious diseases, rising birth rates and declining infant mortality in the developing world, improved sanitation, and enhanced access to medical care. Developing nations are likely to account for around 97% of this growth, with Africa alone accounting for 49% of global population growth by 2050. As the population grows it is also aging—over the next 30 years the median global age will increase from 29.6 to 36.1, with 1.4 billion people over the age of 65. Climate change, civil unrest, and the shifting global economic landscape will also drive an increase in migration. While migratory flows from the developing to the developed world will continue, we may see increased migration within the developing world as economies in Africa and Asia continue growing toward mid-century.

Technology will both reinforce and respond to these demographic changes. Advances in medical science will contribute to a reduction in deaths due to disease, genetic conditions, and lifestyle-related illness. Medical advances will also reduce child and mother mortality, especially in the developing world. Life extension technologies will also increase the number of senior citizens who remain productive well into their 70's and 80s. At the same time, an overall increase in the population will drive greater demand for health care analytics and robots designed to assist the elderly. Migration will create additional demand for communications technology as immigrants seek to maintain ties to friends and family in other parts of the world. In addition to mobile communications, technologies like virtual and augmented reality could allow immigrants to "visit" their homes and maintain contact with their own cultures. Migration could also encourage governments to develop new applications for analytics to track migratory flows—which could have unintended consequences if used for racial or ethnic profiling.

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Globalization of Innovation

Globalization has been underway for the past 30 years, and shows no sign of slowing as we move toward mid-century. On balance, globalization has expanded economic opportunity across many parts of the developing world and contributed to a broad increase in standard of living. On the other hand, globalization has increased environmental destruction, eliminated manufacturing jobs in the U.S. and other developed nations, and led to various levels of worker exploitation. Over the next 30 years, globalization will extend beyond manufacturing and into services and innovation. As China and India emerge as major players in the global economy we should expect these nations to begin competing with the U.S. in research and development. For example, over the past 5 years, Chinese R&D investment as a share of GDP has grown 34%, from 1.48% in 2010 to 1.98% in 2015. In contrast, U.S. R&D expenditures have remained constant at around 2.8% of GDP over the same period.[18] In the absence of any intervening events, based on forecasts of GDP growth over the next 30 years, China could surpass the U.S. in R&D investment by 2021.

From a technology standpoint, the globalization of innovation will mean that the United States' influence over the global innovation agenda will fade. We are already seeing early signals of this shift: in 2013, China published 629,612 patents—over 200,000 more than the United States.[19] The Chinese National Patent Development Strategy prioritizes seven industries: biotechnology, alternative energy, clean energy vehicles, energy conservation, high-end equipment manufacturing, broadband infrastructure, and high-end semiconductors. Given the massive investments China is making in research and development, it is likely that we will see a spike in innovation in these areas, particularly in areas where Chinese and U.S. investments overlap, such as biotechnology. In the case of energy technologies, China could become the global leader, out-innovating the United States in this critical technology sector.

Rise of Global Middle Class

Membership in the global middle class is expected to more than double over the next 15 years, from 1.8 billion to almost 5 billion. By 2030, 60% of the world's population could belong to the middle class, with the majority of middle class growth occurring in Asia.[20]

The growth of the global middle class will be accompanied by significant growth in levels of education and technology access worldwide – by 2030, around 90% of the world's population will know how to read, and 50% will have Internet access. However, the quality and availability of education and technology will remain uneven, with developed nations holding significant advantages over the developing world well into the 2040s.

As incomes rise, people around the world will have more disposable income to spend on consumer electronics and other goods and services. This could fuel significant innovation across a wide class of technologies. Mobile and cloud computing could receive a significant boost in investment as more people are able to afford smartphones with connections to high speed wireless Internet service. Social technologies would likely grow in parallel as Internet access becomes more widespread. Demand for human augmentation technologies could also grow, especially for less expensive augmentations such as wearables and pharmaceutical enhancements. Blended reality technologies may become more ubiquitous as delivery vehicles for immersive, interactive entertainment and distributed education. Investments in the Internet of Things may grow as the emerging middle class invests in smart home products and governments make investments in digitally-enhanced infrastructure. While the rate of growth in these and other technology sectors will depend on how far global incomes rise, it is likely that the rise of the global middle class will fuel broad-based innovation in science and technology.

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CONCLUSION

This report presented a synthesis of 32 forecasts that address science and technology trends that will emerge over the next 30 years. The objective of this synthesis was to identify trends that are likely to generate revolutionary or disruptive change that will impact the United States Army. By consolidating multiple trend analyses this report aims to provide a ready reference for Army leadership as it considers the important role S&T will play in shaping the future of our Army.

A total of 690 trends were identified within the source documents, and further analysis identified 24 S&T trends along with 6 trends related to broader social, economic, political, and environmental forces that are likely to shape the evolution of science and technology over the coming decades. Many of the S&T trends discussed in this report relate to the growing role of digital and networked technologies in our everyday lives. Over the next 30 years, it is likely that the gap between humans and technology will continue to narrow as autonomous systems become commonplace, human augmentation interfaces biological and physical hardware, and computation proliferates through the Internet of Things. In addition, innovations such as additive manufacturing are empowering individuals and corporations with new tools for molding our physical environment, while social technologies are empowering individuals to craft their own micro-cultures and redefine traditional power structures. In the world of biotechnology, synthetic biology reflects an emerging capability to engineer the fundamental genetic building blocks of life itself. Underlying many of these emerging technological changes is a revolution in our ability to apply analytics to understand patterns in complex data, and visualize these patterns to uncover insights that power more effective decisions. As global populations expand, and climate change stresses food and water security, technology will become essential to keeping the global population healthy, safe, and productively employed.

All of this progress in science and technology is likely to take place against a backdrop of larger socio-political, economic, and environmental trends. Urbanization will lead to a proliferation of mega-cities that become major centers of political and economic influence—and will make or break nations in the years ahead. Climate change is, in many respects, a trend that could have the most profound effects on geopolitical stability and the evolution of new technologies. If the worst-case scenarios for climate change come to pass, we will experience massive food and water shortages across both the developing and developed world. Extreme weather will wreak havoc on rapidly expanding cities, creating immense humanitarian crises and an ongoing drain on the global economy. Even under less catastrophic forecasts, climate change will drive unrest and resource competitions that will draw the U.S. Army into new operations around the globe. In concert with climate change, resource constraints related to food, water, energy, and raw materials could slow economic expansion and lead to significant instability in many parts of the world. As the global population grows, it is also aging, and migratory flows will generate continued opportunities for revitalization and challenges of integration and social harmony. Innovation will also migrate, as China, India, and other developing nations emerge as major players on the economic stage. China, in particular, is poised to catch up with the United States in research and development investments, a development that would have profound consequences for the U.S. economy, global security, and the global innovation agenda. Finally, there is a general trend toward the broadening of the global middle class. Over the next 30 years, hundreds of millions of people worldwide will be lifted out of extreme poverty. While this will greatly reduce human suffering, there will still be vast inequalities that drive class tensions, and growing consumption could exacerbate resource stress and climate challenges.

Taken together, these S&T and contextual trends present a number of strategic questions for the Army as it looks to evolve a resilient strategy for the coming decades:

- *Apart from major changes in the acquisition process, how can we posture the force to benefit more rapidly from technological innovation, particularly by leveraging commercial research and development efforts?*
- *Assuming innovation becomes globalized, how can the Army better work with foreign governments and international research and development centers to ensure that the Army has access to the best available technology, which might very well come from outside the United States?*
- *Human augmentation and autonomous systems have the potential to revolutionize almost every warfighting function. Is the Army prepared for the changes these technologies will bring? Are we prepared to face adversaries that employ these technologies against us? How far are we willing to go in giving robots autonomy or permanently modifying Soldiers' bodies and minds?*
- *How can the Army better partner with the joint community, international partners, NGOs, and other stakeholders to influence government and industry-backed R&D agendas to a) deliver new capabilities for maintaining security, b) prevent adversaries from co-opting technological innovation to their own ends, and c) prevent many of the potential "dark sides" of S&T trends from creating new security challenges?*
- *How can the Army foster emerging innovators, including start-ups, that fall outside the traditional defense industrial base? On the flip side, how can the Army encourage innovation at its own research and development centers?*

Science and technology will undoubtedly transform many aspects of life over the next 30 years. While it is impossible to accurately predict the future in detail, the trends discussed in this report will likely influence the course of the world, with important ramifications for the U.S. Army. The intent behind this report was to inform Army leadership about where the future might be headed and raise questions about how we might best prepare the force for a dynamic and uncertain future. Technological change will present both challenges and opportunities for the Army and the nation in the coming decades. Strategic thinking will be critical for understanding how to capitalize on S&T trends to prepare the force for the road ahead.

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Trend Identification Methodology

Emerging S&T trends were identified through a three-step process of Scanning published trend forecasts, Clustering using semantic analysis to isolate common topics, and Coding to identify emerging trends.

Scanning involved a comprehensive literature search for open source trend forecasts published by foreign and domestic government agencies, industry analysts, academic organizations, and think tanks. A total of 32 forecast reports were identified based on the following criteria:

- *All of the reports had to be the product of rigorous and well-documented research conducted by reputable organizations with a track record of producing high-quality trend analysis.*
- *All of the reports had to have been published within the past 5 years.*
- *All of the reports had to address science and technology trends that could influence Army operations and the future operating environment over the next 30 years.*
- *All of the reports had to address a wide range of science and technology trends. Narrow forecasts related to highly specific industries or technology domains were not included in this analysis.*

Overall, 9 sources were carried over from the 2015 Emerging Trends report, while 23 new sources were added. Each document was carefully reviewed for discussions of emerging trends that are likely to impact science, technology, and the Army over the next 30 years. In all, this review isolated 690 specific trends from the source documents. A Microsoft Excel database was created to store citation information for each document-specific trend along with page numbers and quotes to support further analysis.

Based on this data set, the next step was to synthesize a set of emerging S&T trends. An initial set of candidate trends was developed using latent semantic analysis (SA), a statistical approach for identifying similarities among a collection of texts.[1] Among other applications, LSA and related techniques are widely used in search engines to match user queries against website content. For the present analysis, LSA was used to identify clusters of trends that shared a common semantic meaning. This involved 5 steps:

1. *Quotes from the trend database were pre-processed to remove punctuation and stopwords, which are common words such as "the" that do have any information value relative to the meaning of the text samples.*
2. *The text data were then tokenized, which involved transforming each quote into a vector containing all of the unique words that appeared in the quote and counts of word frequency.*
3. *A term frequency-inverse document frequency (tf-idf) model was then fitted to the tokenized data. Tf-idf is a numerical statistic that measures the importance of a word to a particular text. In this case, tf-idf was used to measure the importance of particular words to each entry in the database. The tf-idf value is proportional to the number of times a word appears in a text, offset by the frequency of the word in the database, which adjusts for the fact that some words are more frequent in general. This approach gives greater weight to unique words that are likely to carry greater meaning, and hence are better reference points for identifying clusters of related data.*
4. *Results from the tf-idf model were then used to compute the cosine similarity among the trends. Cosine similarity is a measure of the similarity between a pair of texts. In this case, a cosine similarity matrix was created that gave a numerical score for the similarity between every quote in the database.*
5. *Cluster analysis using Ward's method[2] was then used to identify a preliminary set of emerging trends based on the cosine similarity matrix. Unlike other clustering routines such a k-means, Ward's method does not require the analyst to pre-determine the number of clusters. Therefore, it can be used in an exploratory manner to identify the optimal number of clusters within a data set. This cluster identification was the focus of the Coding phase, described below.*

The Coding phase involved qualitative analysis and adjustment of the clusters that resulted from the statistical analysis to identify a coherent set of themes. This step was essential for producing a final set of emerging trends because it compensated for known limitation of LSA. For example, LSA cannot handle polysemy—words that have multiple meanings. Similarly, LSA has only limited ability to detect deep structure based on contextual cues. In essence, LSA is useful as a first pass for identifying potential clusters of common trends, but human judgment is still required to make sure that these clusters make sense. Combining quantitative (LSA) and qualitative coding supported an objective analysis while ensuring that the emerging trends accurately reflected the original source documents.

Coding revealed 24 common science and technology "mega-trends" that have the potential to shape future Army operations and the future operating environment. In addition, six cross-cutting contextual trends were also found that will influence how science and technology could evolve over the next 30 years. While the S&T trends are the focus of this report, the contextual trends provide valuable insight into non-technical forces that are likely to shape research and development priorities among governments, industry, and academia.

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Concurrence and Share

Having synthesized a set of 24 emerging science and technology trends, additional analysis was focused on understanding the relative emphasis that these trends received from the source documents. This analysis centered on measuring consensus across the sources for each core trend. Consensus within the source reports for certain trends can be a useful measure for thinking through the likelihood that a given trend will have a tangible impact on the future. From a sampling perspective, trends that are drawing a great deal of attention should have a greater chance of generating broad-based impact than trends that are only mentioned a handful of times. Obviously, frequency is an imperfect metric—experts can fall prey to hype, and technologies that appear smaller on the radar of collective wisdom can undergo sudden, disruptive innovation. Nonetheless, frequency-related metrics can help shed additional light on how much attention particular trends are getting among experts within governments, industry, think tanks, and other organizations.

With this in mind, two measures of frequency—concurrence and share—were calculated for each trend. Concurrence measured the percentage of source reports that made mention of a particular trend. Values ranged from 76.67% (23 out of 30 sources)[3] for Robotics and Autonomous Systems to 10.00% (3 out of 30) for Changing Nature of Work. Figure 1 depicts the Concurrence values for all 24 emerging S&T trends. showing Concurrence provides insight into how many reports discussed each trend. In contrast, Share measured the percentage of entries in the entire source document database that were related to each trend. In other words, Share measured how often each trend was mentioned in the context of every S&T-related forecast found in the source documents. Certain trends are discussed multiple times in a given report. Therefore, Share provides insight into the relative amount of focus given to each trend across the entire dataset. Share ranged from 10.59% (50 out of 472 technology-related entries) for Robotics and Autonomous Systems and Social Empowerment, to 0.85% (4 out of 472 entries) for Education. Figure 2 depicts the Share values for all 24 emerging S&T trends.

Figure 1

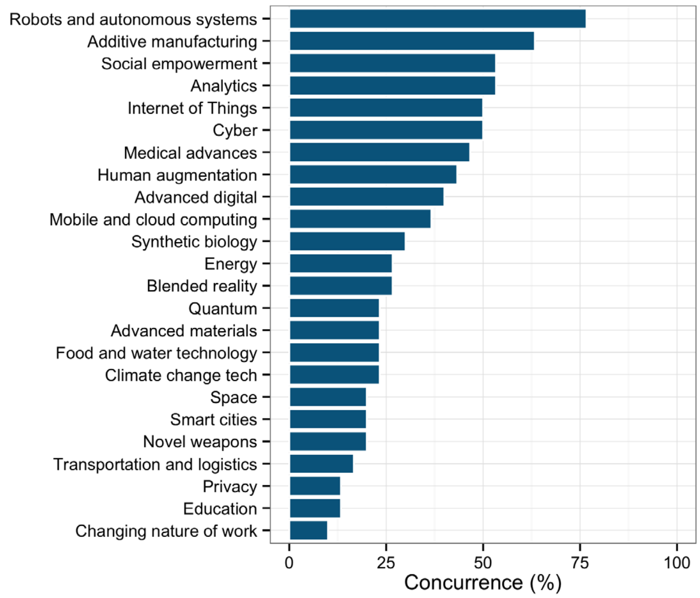
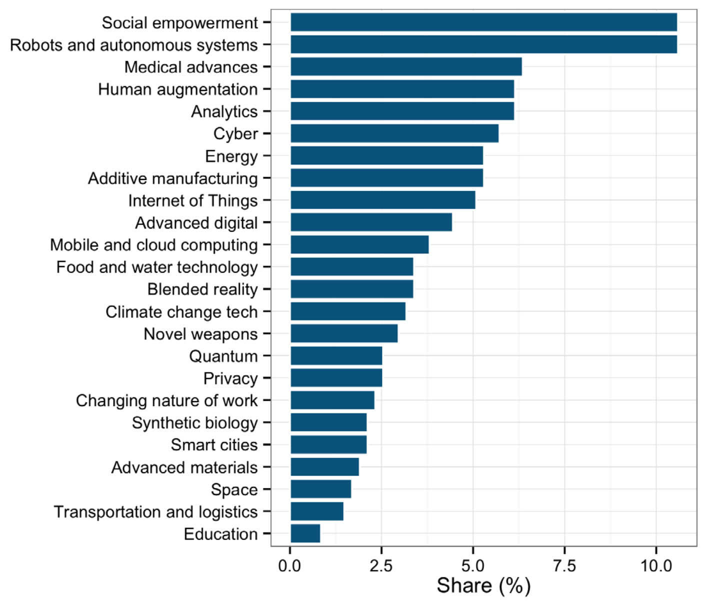


Figure 2



3. *Two of the source documents (Australia's Future Land Warfare and KPMG's Expect the Unexpected) made general references to technological developments, but did not contain any detailed analysis of technology trends. These sources were used to identify contextual trends, but were not counted in the Concurrence and Share analysis.*

ROBOTICS AND AUTONOMOUS SYSTEMS

76.67%
CONCURRENCE

10.59%
SHARE

By 2045, robots and autonomous systems are likely to be commonplace. Autonomous vehicles will make transportation safer and more efficient, while possibly fueling the rise of the sharing economy. Robots will care for the elderly, deliver groceries, harvest crops, maintain public infrastructure, and provide many other services that touch everyday life. Intelligent software agents, or "bots", will extract insights from terabytes of data, automate business processes, and step into customer service, teaching, and other roles traditionally seen as "people-centric".

However, the rise of autonomous systems could displace hundreds of millions of labor and service workers, creating economic instability and the risk of social unrest. Networked autonomous systems will also become an attractive target for adversaries and a new priority for cyberdefense. The use of robots in military operations will expand as robotic systems gain mobility, dexterity, and intelligence, making robots effective partners on future battlefields. At the same time, adversaries will use robots and autonomous systems in ways that challenge us ethically and tactically.

ENABLING S&T

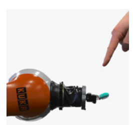
» Machine Learning
Learning is critical for autonomous systems to adapt to novel, complex environments. Impressive strides are being made in deep learning, inspired by a growing understanding of how learning occurs in biological nervous systems.

» Sensors and Control Systems
To interact safely, usefully, and effectively with humans in real-world environments, robots and other autonomous systems will need richer internal models of their environments linked with more flexible movement capabilities.

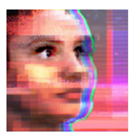
» Human–Machine Interaction
We are just beginning to understand how to design autonomous systems that can partner with humans to perform complex, real-world tasks. Research on natural language communication and empathic robots will help bridge the human-machine divide.

SIGNALS

» AlphaGo
AlphaGo, developed by Google's artificial intelligence wing Deepmind, became the first computer capable of beating human champions at the ancient game of Go. Notably, AlphaGo was not specifically programmed to play the game. Instead, it taught itself to play by studying 30 million board positions from expert games.



» Robot Nervous System
Researchers, from Germany's Leibniz University, are developing an "artificial robot nervous system" that will enable robots to "feel pain" and quickly respond in order to avoid potential damage to their motors, gears, and electronics.



» Tay
In March 2016, Microsoft unveiled Tay, a "Twitter-bot" designed to talk like a teenage millenial. The bot learned how to communicate by analyzing tweets it received from human users. Unfortunately for Microsoft's public relations department, Tay's tweets became increasingly inappropriate as an army of Internet trolls fed the bot a steady stream of offensive material. The company took Tay offline after less than a week.

IMPACT

» Social
Robots will become part of the social landscape. As autonomy and intelligence grows, these systems will raise difficult questions about the role of personal responsibility and "machine rights". Loss of jobs to automated systems could lead to significant social unrest.

» Political
As robots become integrated into society, governments will face challenging legal and regulatory issues around how much autonomy robots should be granted and how to assign responsibility when robots break the law.

» Economic
Robotics will transform work, eliminating the need for a wide variety of manual labor and taking over many service jobs. While the gains in efficiency and cost will be a boon for global markets, the loss of jobs across multiple industries will create significant pressure on economies worldwide. A recent study by a pair of Oxford University economists found that machines could eliminate 47% of jobs across every economic sector.

» Environmental
As autonomous systems become more prevalent, it will also become important for robots and other autonomous agents to be capable of coordinating with each other. Research on swarm robotics demonstrates how robots and other autonomous system might communicate and cooperate.

» Defense
As robots become more capable, the U.S. Army will have to reevaluate the role of the Soldier in combat. Robots will revolutionize just about every aspect of military operations. Their ubiquity will mean that our adversaries will also use robotic systems, and they might be willing to go further than us in giving combat robots complete autonomy.

While these systems make a strong contribution to productivity and can perform jobs which are dull, dirty and dangerous for humans, there is a danger of them eliminating a large number of jobs in a relatively short time frame. Almost 50% of all jobs could be automated in the next 20 years.

— European Commission Foresight Network 2030

Automated systems offer almost unlimited potential, yet using them is likely to be more constrained by legal and ethical concerns than by the limits of the technology itself. However, some actors may not be bound by such concerns, potentially developing combat systems that may target people indiscriminately.

— UK Ministry of Defense

ADDITIVE MANUFACTURING

63.33%
CONCURRENCE

5.30%
SHARE

Additive manufacturing (3D printing) has been used in industry for over 30 years, mostly as a tool for limited-run prototyping. However, there has been remarkable innovation in 3D printing technology over the past ten years. Prices for 3D printers are falling, and the availability of open source tools and 3D models from online marketplaces like Thingiverse has fostered the growth of a vibrant community of hobbyist "makers" who are pushing the boundaries of what this technology can do. By 2040, 3D printers will be able to print objects that incorporate multiple materials, electronics, batteries, and other components. People will be able to print tools, electronics, replacement parts, medical devices, and other products on demand, customized to their wants and needs. Military logistics will likely become streamlined, as equipment and supplies will be printed directly at their point of use. Objects will become information, and digital piracy will replace shoplifting. Terrorists and criminal organizations will print weapons, sensors, and other equipment using raw materials that will be almost impossible to track.

ENABLING S&T

» Improving Speed, Size, and Reliability

Outside of high-end industrial systems, today's commercial 3D printers are relatively slow, have a limited print volume, and are often prone to quality issues (this is especially true of lower cost consumer-grade printers).

» Materials

Most 3D printers currently on the market print objects from ABS or PLA plastic filament. Higher-end production printers can also use a limited range of metal powders. Future applications will require printers that can combine a wide range of materials to create complex objects.

» Bioprinting

Bioprinting is an emerging area of research that could revolutionize medicine and food production. Scientists and engineers are working on techniques that could allow doctors to 3D print replacement organs, and some companies are beginning to experiment with 3D printing food.

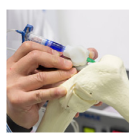
SIGNALS

» Multimaterial 3D Printing

Stratasys, the largest manufacturer of 3D printers in the world, recently unveiled its J750 industrial printer, which is able to print complete objects that involve multiple materials in 360,000 different color shades. The company has demonstrated printing a complete athletic shoe, featuring a mix of plastic and rubber-like materials in multiple colors.

» 3D Printed Pedestrian Bridge

A team of industrial designers, engineers, and architects from the Netherlands is building the world's first 3D printed pedestrian bridge. The bridge will be printed on-site using a pair of large, six-axis printers developed by Amsterdam-based MX3D.



» Biological Ink for Surgical Repairs

Researchers at Australia's University of Wollongong are developing the BioPen, which will enable orthopedic surgeons to repair damaged bone and cartilage by "drawing" new cells directly onto a wound. The device uses a biological "ink" made from stem cells and biopolymers. Cells deposited by the BioPen onto bone have a 97% survival rate.

IMPACT

» Social

3D printing, combined with social media technology, could move "maker" culture into the mainstream. People will be able to collaborate, customize, and share design files in ways that will be difficult to predict or control.

» Political

3D printing raises serious questions around protecting intellectual property. Imagine the complexity of policing online piracy of music, movies, and software. Now apply the same difficulties to every physical object.

» Economic

Additive manufacturing will make it possible to do low-rate production and customization cost-effectively. This could create an economic impact of over $500 billion per year across multiple industries.

» Environmental

Additive manufacturing is extremely efficient and generates far less waste that molding or machining. Point of use production could also reduce pollution from transporting goods across countries and continents.

» Defense

3D printers could transform military logistics by allowing units to print equipment and spare parts in the field. At the same time, adversaries will be able to print weapons and other equipment from plans that are stolen, reverse-engineered, or or traded on illicit networks.

Additive manufacturing could fundamentally impact the defense industrial base—and the manufacturing process writ large—by dramatically increasing the pace of moving from prototype to production and by enhancing the flexibility and adaptability of production lines.

— Center for a New American Security

We estimate that 3D printing could generate economic impact of $230 billion to $550 billion per year by 2025 in the applications we have sized. The largest source of potential impact among sized applications would be from consumer uses, followed by direct manufacturing and the use of 3D printing to create tools and molds.

— McKinsey Global Institute (MGI)

ANALYTICS

53.33%
CONCURRENCE

6.14%
SHARE

In 2015, the world generated 4.4 zetabytes of data (4.4 trillion gigabytes), and this figure is expected to roughly double every two years. This flood of data holds deep insights into consumer behavior, public health, climate change, and a range of other economic, social, and political challenges. However, while "Big Data" has become a buzzword, less than 10% of data generated each year ever gets analyzed. Over the next 30 years our ability to make better use of massive, dynamic data sets will improve. Automated bots will crawl unstructured data, identifying relationships that are visualized in immersive virtual datascapes.

Analytics will spread beyond the enterprise, as people gain the ability to apply big data to their personal lives. Citizens will have the ability to use data to hold governments and other major institutions accountable, leading to tensions over data access. The rise of hyper-personalized marketing, government surveillance of citizens' data trails, and high profile cases of data loss could fuel growing concerns over data ownership. Potential adversaries will use data that is stolen, purchased off dark networks, or accessed freely from open sources to compromise security and challenge U.S. defense capabilities.

ENABLING S&T

» Visualization

We need better visualization techniques that allow human decision-makers to understand patterns in complex, multi-dimensional data sets.

» Automation

Automated analysis algorithms can identify statistical patterns in massive data sets that would be difficult for human analysts to spot. Techniques like deep learning open the possibility of automating analysis of the immense amount of unstructured data (i.e., images) that is time-consuming and cognitively demanding for people to process.

» Natural Language Processing (NLP)

NLP uses computer algorithms to analyze patterns in unstructured text data such as text messages.
One application of NLP is using sentiment analysis on social media to determine how people are reacting emotionally to a particular topic.

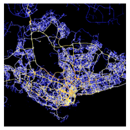
SIGNALS

» Deep Learning Supercomputer

Massachusetts General Hospital has partnered with NVIDIA to explore how the California-based company's DGX-1 Deep Learning Supercomputer can transform how physicians use data to detect, diagnose, and treat diseases.

» Predictive Policing

Police departments are beginning to use "predictive policing" to identify patterns in local crime data. The technology, which some have likened to the 2002 film Minority Report can help detect conditions that give rise to crime. At the same time, activists have expressed concern that the use of analytics might lend an air of scientific credibility to heavy-handed police tactics and disproportionate targeting of minorities.



» Singapore's Smart Nation Platform

As part of its Smart Nation Initiative, Singapore is developing a nationwide platform of networked sensors and data analytics tools to monitor traffic, pedestrian movement, weather, and other variables. Singapore will use its Smart Nation Platform to manage traffic flows, analyze new construction proposals, and coordinate emergency response.

IMPACT

» Social

Mastering big data analytics will have a profound impact on health care. For instance, epidemiologists will be able to better understand interactions among genetic and environmental factors in cancer, heart disease, diabetes, and other diseases.

» Political

As Wikileaks, Anonymous, and Edward Snowden have shown, there are difficult political issues around who should control data and decide how it should be used. As analytic capabilities mature the information value of data will increase, as will the pitfalls of data access.

» Economic

Big data analytics will touch most economic sectors by 2040. If current growth trends hold, the combined market impact of analytics will exceed half a trillion dollars by 2020.

» Environmental

The ability to effectively draw insights from massive amounts of climate data will revolutionize climate modeling, enabling better predictions of climate change and weather.

» Defense

Analytics will transform the ability to draw actionable intelligence from the sea of sensors that will exist on future battlefields. A commercial market for personal, wearable sensors will drive innovations in monitoring individual Soldier performance. At the same time, as analytic solutions become widely available, adversaries will be able to exploit civilian sensor networks to collect intelligence at little to no cost.

Yes, data technologies are evolving rapidly, but most have been adopted in piecemeal fashion. As a result, enterprise data is vastly underutilized. Data ecosystems are complex and littered with data silos, limiting the value that organizations can get out of their own data by making it difficult to get to.

— Accenture

Access to information has until now only let us understand the past, leaving it to people to extrapolate and imagine what this may mean for the future. Big Data is increasingly allowing us to predict future behaviours accurately.

— UK Ministry of Defense

CYBER

50.00%
CONCURRENCE

5.72%
SHARE

Cyberdefense is hardly a new trend—warnings about a "cyber Pearl Harbor" were made as early as 1991. However, over the next 30 years the rise of the internet of things and growing interdependence among connected aspects of everyday life will bring cybersecurity to the forefront. While the number and scope of cyberattacks is increasing, most have been targeted against individual consumers or corporations and the damage from individual attacks, while extensive, has been easily contained. As cars, home appliances, power plants, streetlights, and millions of other objects become networked, the potential for a truly devastating cyberattack will grow. Nations, corporations, and individuals will be challenged to secure their data from ever more insidious attacks—many of which may go undetected for years. The worst-case scenario envisions a form of "cybergeddon", in which the immense economic and social power of the Internet collapses under the weight of relentless cyberattacks.

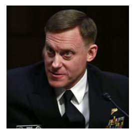
ENABLING S&T

» User Authentication Technologies
Future authentication techniques will use biometrics, personal cryptographic key generators, and other technologies that provide stronger and simpler access control than today's passwords.

» Resilient Networks
Research in underway to build networks that are self-configuring, self-healing, self-optimizing, and self-protecting.

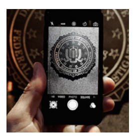
» Next Generation Encryption
Quantum cryptography is one example of future encryption technologies that will make it more difficult for cyberattackers to make use of stolen data.

SIGNALS



» CYBERCOM
Admiral Michael Rogers, commander of U.S. Cyber Command (CYBERCOM), recently argued before Congress that CYBERCOM should be elevated to the level of a unified combatant command, on part with CENTCOM, AFRICOM, and the other Commands.

» Oceans 00001011
Hackers tried to steal a total of $951 million from an account owned by the central bank of Bangladesh that was being held at the Federal Reserve Bank of New York. While most of the attack was blocked, it was the largest attempted cybertheft in history. A Philippine Senator blamed Chinese hackers, an accusation that the Chinese government quickly denounced.



» Privacy vs. Security
In March of 2016, the FBI announced that it had, with the help of an Israeli cyber security company, successfully broken the encryption on an iPhone owned by San Bernardino shooter Syed Farook. The government-led hack came after Apple refused to break the encryption themselves, sparking a high profile public battle with the FBI over privacy rights. Apple argued that breaking the iPhone encryption would weaken cybersecurity for millions of consumers.

IMPACT

» Social
While the Internet and other networks have proved resilient to most cyberattacks, ongoing security breakdowns and revelations about domestic monitoring of digital activity could further undermine people's trust in governments and corporations.

» Political
Governments will be challenged to enact both domestic cyber policies and international protocols and standards governing cybercrime and cyberespionage.

» Economic
A recent analysis by security firm McAffee estimates that cyberattacks cost the global economy $375-575 billion per year. This figure will continue to grow as more devices come online and cyberattacks become more sophisticated.

» Environmental
Environmental hacktivism is an ongoing source of risk for businesses and governments. In coming years hactivist cyberattacks will affect energy infrastructure such as power plants and pipelines as well as financial and transportation networks.

» Defense
Cyber creates new avenues for crippling adversaries without using lethal force. However, dependence on networks exposes U.S. forces to tremendous risk.

Cybercrime is accelerating at an exponential pace. In the not-so-distant future, everything from our watches to the EKG monitors in hospitals will be connected to the Internet and ready to be hacked.

— Deloitte

The next generation could grow up with a cyberspace that is less open, less resilient and fundamentally less valuable than the one existing today. The most transformative technology since Gutenberg would regress, to the loss of societies, economies and humanity.

— WEF

ENERGY

26.67% CONCURRENCE

5.30% SHARE

Over the next 30 years the global demand for energy is projected to grow by 35%. The development of methods like fracking and directional drilling have opened vast new reserves of oil and natural gas. These technologies have up-ended global oil markets and turned the United States into one of the world's largest fossil fuel producers. At the same time, renewable energy sources such as solar and wind are approaching cost-parity with fossil fuels. In the past two decades, the cost of power produced by solar cells has dropped from nearly $8 per watt of capacity to less than one-tenth of that amount. Nuclear, while still the subject of intense public debate, is continuing to grow, with new reactor designs promising greater safety and less radioactive waste. While adoption of cleaner energy sources would help combat global climate change, new frictions will emerge over access to rare materials used in batteries, solar cells, and other linchpins of the energy revolution. The fading of fossil fuels also carries significant risk of economic and social destabilization across the Middle East and North Africa, presenting new security challenges for the United States and its allies.

ENABLING S&T

» Solar Efficiency

Research into new materials continues to increase the efficiency of solar panels while reducing their cost. At current growth rates, the cost per watt of solar could drop below 50 cents over the next 20 years.

» Battery Technology

Batteries are key to managing uneven power output at solar and wind generation facilities. Battery researchers are exploring new chemistries that can store greater amounts of power in less space and for lower cost.

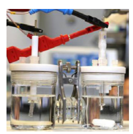
» Energy Harvesting

The planet is awash in energy. Beyond solar, wind, and biofuels, research and development projects are expanding our ability to harvest energy from geothermal heat, tidal power, and other unconventional sources.

SIGNALS

» Green Energy on the Rise Worldwide

According to a report published by the United Nations Environment Program (UNEP), the world invested $286 billion in green energy in 2015, an increase of 3% over the previous record set in 2011. China, the world's largest emitter of greenhouse gases, led the way in green energy investments, committing about a third of total worldwide investments, or $102.9 billion. The United States, the second largest emitter, is a distant second with $44.1 billion in new investments – 20 percent less than it invested in 2014.



» Improving Hydrogen Fuel Cell Efficiency

Scientists at East China University of Science and Technology have developed a tungsten-based gel that can generate hydrogen from water molecules three times faster and at a significantly lower cost than current technologies.

» Crude Oil Price Collapse

A glut of crude oil caused by overproduction by OPEC and surging production in the Unites States and other Western nations, has sparked an unprecedented slump in global oil prices. Oil has fallen from around $115 a barrel in the summer of 2014 to a low of $27 at the beginning of 2016. While industry analysts expect prices to rebound in 2016, the price shock has rocked oil-dependent economies like Nigeria, which relies on oil for 70% of its GDP.

IMPACT

» Social

As a global middle class emerges, power and energy will become the glue that keeps civil societies together.

» Political

Climate change and environmental risks from nontraditional fossil fuel extraction will drive global political debates over the role of oil and natural gas versus expanded use of renewable energy sources.

» Economic

Domestically, the discovery of massive oil and natural gas reserves will bolster the US economy. Globally, the emergence of renewable fuels will spark new industries and reduce barriers to power generation in developing nations.

» Environmental

Oil and coal will still provide the bulk of the global energy budget through at least the 2030s. Continued reliance on fossil fuels will increase atmospheric CO2, driving additional climate change. Negative effects could be offset by alternative energy technologies that are cost-competitive with fossil fuels.

» Defense

The prospect of US energy security will significantly reshape the strategic environment. While we become less dependent on foreign sources of energy, traditional oil- producing powers could experience significant economic disruption, opening the door for extremist ideologies to take root.

The center of gravity of world energy markets is shifting from the Persian Gulf to the Western Hemisphere (US, Canada, Mexico, Brazil). This shift has already reduced US dependency on oil imports from 60 percent in 2005 to 39 percent in 2013 with prospects for US self-sufficiency on the horizon. Strategically, it may bolster the US "rebalance" in Asia as well as spark a rethinking of US Middle East strategy.

— Atlantic Council

Delivery of energy products will be replaced by delivery of energy services, breaking the current geographical and temporal links between power generation and consumption. Distributed electricity production will increase its share in the generation mix. Next to electricity, hydrogen will become a major energy carrier in an increasingly integrated power-transport-heat system.

— European Commission Foresight Network 2030

FOOD & WATER TECH

23.33%
CONCURRENCE

3.39%
SHARE

Over the next 30 years, inadequate access to food and fresh water will become a crisis point in many parts of the world. Roughly 25% of current farmland is already degraded from overfarming, drought, and air/water pollution. Under optimistic forecasts, prices for staple grains could rise by 30% over the coming decades—increases of 100% are not out of the question if climate change, demand patterns, and failed resource management continue on current trajectories. By 2045, 3.9 billion people—over 40% of the world's population—could face water stress. Technology offers many potential solutions to food and water crises. Desalination, micro-irrigation, water reclamation, rainwater harvesting, and other technologies could relieve pressure on fresh water supplies. Genetically modified crops and automation could improve crop yields and allow farmers to produce more nutrition from less land. Food and water, long taken for granted in the developed world, will become a major focus for innovation, and could become a major flashpoint for conflict.

ENABLING S&T

» Agricultural Technology

Research on transgenic crops will produce drought and disease-resistant crops with improved agricultural yields. Precision agriculture will bring big data analytics to crop management. Technologies like robotic automation and micro-irrigation (which improves water delivery to crops by 32-95%) will make farming more resource efficient and productive.

» Water Reclamation and Harvesting

In addition to improved desalination technology, development is underway on filtration systems that can produce potable water from nontraditional sources such as rainwater and muddy or contaminated water.

» Alternative Food Sources

Closed-system hydroponics, vertical urban farms, and other new technologies are enabling crops to be grown without access to arable land. Scientists are working on methods for "growing" meat from laboratory cultures, which could improve access to protein without the environmental and resource impact of raising animals for meat.

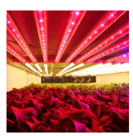
SIGNALS

» Agricultural Drones

Agricultural drones have been attracting significant attention from venture capitalists. Venture investment in agricultural drones reach $4.25 billion in 2015, doubling the amount invested in 2014. By 2022, the global market for agricultural drones is forecast to be $3.69 billion per year.

» Harvesting Water from Fog

CloudFisher is a novel take on a centuries-old concept—harvesting water from fog. The technology, which is being developed by Dar Si Hmad, a Moroccan NGO, in partnership with several German research and engineering organizations, uses large, black polymer nets mounted on poles at elevations over 4,000 feet. The nets trap fog, which condenses and runs into collection tanks. CloudFish can harvest up to 17 gallons a day per square yard of netting—enough to provide much of the water needed by local tribes.



» Vertical Farming

New Jersey-based AeroFarms is building the world's largest vertical farm inside a 69,000-square-foot warehouse in Newark. Once it begins production in Spring of 2016, the farm will produce 2 million pounds of leafy greens a year. The plants will grow in trays stacked 30 feet high, lit by LED lights tuned to optimize photosynthesis.

IMPACT

» Social

Food and water are essential to human life, and disruptions to these vital resources could have significant social impacts, leading to loss in trust in civil governments, rioting, theft, and hoarding.

» Political

Resource management is likely to become an important focus for domestic and international politics. With over 500 rivers and aquifers shared by two or more nations, transnational water control could become a flashpoint. Nations that have historically provided food aid might have to pull back on agricultural exports to feed their own populations.

» Economic

Food and water technologies will be a growth industry over the next 30 years. At the same time, food and water shortages could worsen economic instability and exacerbate class divisions. Today, the world's poor get by on 5-10 liters of water per day, while members of the growing global middle and upper classes use 50-150 liters daily.

» Environmental

Genetically modified organisms (GMOs) have the potential to boost agricultural yields in the face of drought, disease, and degraded farmland. However, the environmental impact of GMOs is uncertain, and many worry that transgenic crops could damage ecosystems if released into the wild.

» Defense

Food and water crises represent dangerous flashpoints for conflict. Some of the world's poorest regions are the most vulnerable to pressures on agricultural output and fresh water supplies caused by climate change and population growth.

Agricultural productivity in Africa, particularly, will require a sea change [sic] to avoid shortages. Unlike Asia and South America, which have achieved significant improvements in agricultural production per capita, Africa has only recently returned to 1970s' levels.

— U.S. National Intelligence Council

In the future, geopolitical tensions over access to strategic water resources could become more systemically impactful, and water shortage coupled with poverty and societal instability could weaken intra-state cohesion.

— WEF

HUMAN AUGMENTATION

43.33%
CONCURRENCE

6.13%
SHARE

Over the next 30 years, technology will allow us to transcend biological limits on human potential. Wearable devices connected through the Internet of Things will deliver context-sensitive information overlaid directly onto our senses. Exoskeletons and brain-interfaced prosthetics will make us stronger and restore mobility to the elderly and infirm. Sensors and computers embedded in contact lenses and permanent implants will let us hear whispers behind walls, give us natural night vision, and allow us to immerse ourselves in virtual and augmented realities. Nootropic drugs will expand our cognitive abilities and transform work and education. Of course, augmentation technology will come at a price, and those who cannot afford to upgrade their "human chassis" might find themselves unable to compete in the augmented economy. Networked augmentations will also be an appealing target for hackers looking to control over our very minds and bodies. While the U.S. Army will benefit from augmenting its Soldiers, the force will face adversaries who are similarly enhanced, and an augmentation arms race could evolve.

ENABLING S&T

» Wearable Computing

Advances in low-power, miniaturized sensors and processors are fueling a new generation of wearable devices that can monitor physical activity, heart rate, and sleep, record environmental conditions, and connect with user-friendly analytics apps. As this technology progresses, people will be able to use rich data to understand and improve their performance.

» Exoskeletons and Prosthetics

Exoskeletons are undergoing rapid development, with research and development focused on new control architectures, power for sustained operation, and optimizing the human-system interface. The ability to interface prosthetics directly with the human nervous systems is also rapidly improving.

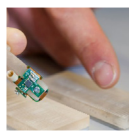
» Pharmacological Enhancement

While there is a large and growing market for cognitive enhancers, the science of using pharmaceuticals to enhance mental performance is still young. While drugs like Modafinil and Adderall are widely used to boost performance, research is ongoing to find other nootropic drugs that can improve mental and physical performance without side effects.

SIGNALS

» Exoskeletons Restoring Mobility

The Spanish National Research Council and its spin-off company Marsi Bionics have created an exoskeleton that grants mobility to children with spinal muscular atrophy. Designed for children between ages 3 and 14, the exoskeleton fits around the child's legs and torso, and consists of five robotic joints in each leg that provide support for the child to stand upright and walk.



» A Bionic Finger

Swiss researchers have developed a bionic finger that can enable amputees to feel textures. While DARPA has demonstrated a bionic hand with basic touch sensitivity, the new finger allows patients to distinguish multiple different textures. This represents an important step toward developing prosthetics that behave just like natural limbs.

» Quantified Self

Smartwatches like the Fitbit Blaze and Apple Watch are driving the trend towards the "quantified self", in which people use personal data analytics to improve their performance. These devices are also charting new ground in making wearable technology fashionable, in contrast to Google Glass and other less successful wearable products.

IMPACT

» Social

The ability to transcend innate limits will be liberating, but will also raise difficult questions about what it means to be human. Distinct subcultures could arise around specific categories of enhancement.

» Political

Through 2040 augmentation will be costly, leading to a two-tiered world of enhanced "haves" and "have nots". This will create political unrest and difficult regulatory issues.

» Economic

The market for augmentation technology cuts across multiple economic sectors, including health care, manufacturing, defense, education, and services. Entirely new industries will emerge as new technologies like exoskeletons and neuroenhancers become commercially viable.

» Environmental

Environmental impacts from human augmentation should be limited, though resource conflicts could grow as enhanced humans become more active and longer-lived.

» Defense

Temporary enhancements (exoskeletons, neuroenhancing pharmaceuticals) will revolutionize Soldier capabilities and reduce training time. Powerful permanent enhancements will raise ethical issues. We should expect to face adversaries that are just as augmented as we are. Networked augmentations, such as exoskeletons and prosthetics, could be the target of cyberattacks.

Human-technology fusion. Technology may have a transformative effect on human beings, by boosting not just their physical abilities, but also their intellectual capacity. In addition to organ regeneration, stimulation of cognitive capacities, genetic choices, delayed ageing or even human augmentation may be possible. Over time, this could deeply affect intra-societal relationships, especially between the humans thus transformed and those who are not.

— European Strategy and Policy Analysis System

Obvious alterations of our physical and mental abilities from contact lenses to artificial limbs to ADHD drugs have historically been solely the province of therapy. But we've reached a turning point a phase change in the nature of augmentation where physical enhancements that once served only to bring people with disabilities closer to the perceived norm can now push these same people—and others—past the norm.

— Institute for the Future

INTERNET OF THINGS

43.33%
CONCURRENCE

6.13%
SHARE

According to fairly conservative estimates, there will be over 100 billion devices connected to the Internet by 2045. This will include mobile and wearable devices, appliances, medical devices, industrial sensors, security cameras, cars, clothing, and other technologies. All of these devices will produce and share vast amounts of information that will revolutionize how we work and live. People will use information generated through the Internet of Things (IoT) to make smarter decisions and gain deeper insight into their own lives and the world around them. At the same time, web-connected devices will also automate many monitoring, management, and repair tasks that currently require human labor. The intersection of the IoT, analytics, and artificial intelligence will create a global network of smart machines that conduct an enormous amount of critical business with no human intervention. While the IoT will improve many aspects of economic efficiency, public safety, and personal productivity it will also exacerbate concerns over cybersecurity and privacy. Criminal organizations, terrorists, and adversarial nation states will use the IoT as a new vector for attacking the United States and its allies.

ENABLING S&T

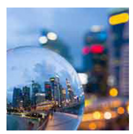
» MEMS
Micro-electromechanical systems (MEMS) make it possible to embed sensors and mechanical actuators in virtually any object. Researchers are creating MEMS with multiple microsensors and microactuators that integrate complex sensing and control functions in micron-scale packages.

» Wireless Communication
Mobile data traffic is forecast to exceed 11 exabytes (11 quintillion bytes) a month by 2017, with continued exponential growth into the foreseeable future. That volume of data will require robust wireless technology with bandwidth management well beyond current capabilities.

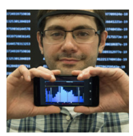
» Power
For many IoT applications, such as embedded sensors, batteries or plugging into electrical outlets will not be practical options for delivering power. Innovation is needed in power efficiency, smart power management, energy harvesting, wireless power transmission, durable power sources (e.g., radionucleotide batteries), and other technologies.

SIGNALS

» Unrealized Potential of IoT
Even though The Internet of Things is starting to generate large amounts of data, most companies are not yet using it. A recent study conducted by Oxford economists found that only 8% of businesses are using more than 25% of their potential IoT data. It is likely that governments and nonprofits are making even less use of IoT data.



» Asian IoT Partnership
The Nanyang Technological University of Singapore and Taiwanese electronics firm Delta Electronics have established a joint laboratory to research and develop "cyber-physical systems" - Internet of Things technologies for manufacturing and smart homes and offices.



» Medical Monitoring
The pharmaceutical company Pfizer is partnering with IBM on an ambitious project to use networked medical devices to enhance research and development of drugs to treat Parkinson's disease. The companies are developing a system of sensors, mobile devices, and analytic software that would provide real-time monitoring of Parkinson's patients and share symptom data with clinicians and researchers.

IMPACT

» Social
The Internet of Things will radically transform societal views on privacy. Sensors will monitor our movements, transmit our vital signs, and listen to our every word. For this to work, trust must exist between individuals, corporations, and governments.

» Political
The Internet of Things presents a host of challenges for privacy rights that will raise challenging domestic and international regulatory issues.

» Economic
The McKinsey Global Initiative estimates that the Internet of Things will have a direct economic impact of $2.7 to $6.2 trillion by 2025, a value that could double or possibly triple by 2045. Economic impacts will be especially strong in health care, manufacturing, and infrastructure.

» Environmental
The Internet of Things will enable smart grids for managing power and water distribution, increasing efficiency, reducing waste, and reducing pollution caused by energy production.

» Defense
The ubiquity of networked devices with embedded sensors will open new vistas for intelligence gathering. At the same time, cyberattacks will become an even greater threat as criminals, terrorist organizations, and adversarial nation states target hundreds of billions of networked devices supporting our economy and infrastructure.

A desire not to be part of the "Internet of Things" may create new markets, for example a holiday resort advertising its facilities with a promise that you will be completely "off-grid". This could also lead to a drive to try to create spaces, both physical and virtual, which are unseen or ungoverned by state authorities around the world.

— UK Ministry of Defense (MoD)

The Internet of Things—embedding sensors and actuators in machines and other physical objects to bring them into the connected world—is spreading rapidly. From monitoring the flow of products through a factory to measuring the moisture in a field of crops to tracking the flow of water through utility pipes, the Internet of Things allows businesses and public-sector organizations to manage assets, optimize performance, and create new business models.

— McKinsey Global Initiative

MEDICINE

46.67%
CONCURRENCE

6.36%
SHARE

Over the next 30 years, medicine will be transformed by multiple technological breakthroughs. Genomics will give rise to personalized medicine, with treatments for cancer, cardiovascular disease, Alzheimer's, and other diseases tailored to individual genetics. Artificial organs will be grown for transplantation from DNA samples, eliminating wait times for life-saving transplants and the risk of organ rejection. Prosthetics will be wired directly into the nervous system and will incorporate biologically based sensors that provide a near-normal sense of touch. Robotic first responders and tissue preservation techniques such as controlled hypothermia will revolutionize trauma care and greatly extend the "golden hour" for wounded Soldiers. As scientists unlock the keys to aging, people will live longer and stay healthy and active well into what today we consider "old age". At the same time, the cost of advanced medical care will stress many national health care systems and trigger rising inequality in access to life-saving treatments. The coming medical revolution will also enable people to remain healthy and productive for decades longer, amplifying competition for jobs between older and younger workers and creating additional strain on social safety nets.

ENABLING S&T

» Personalized Medicine

Pharmaco-genetics could usher in an era of personalized medicine. Detailed understanding of human genetics will enable the development of individualized pharmaceuticals for cancer, autoimmune disorders, neurodegenerative diseases, and other life-threatening ailments.

» Regenerative Medicine

Research is underway that will enable organs, and potentially entire limbs, to be grown from a patient's own genetic material. We will have access to personalized "replacement parts", turning many terminal diseases into manageable repairs.

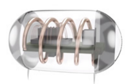
» Biomedical Engineering

Advances in biomedical engineering will lead to prosthetics that almost perfectly mimic the capabilities of natural limbs. Other technologies will transform medical diagnosis and treatment, such as injectable nanobots that will be able to deliver drugs and perform micro-surgeries.

SIGNALS

» Drug Resistant Bacteria

By the year 2050, a study by the UK government estimates that drug resistant bacteria, such as E. coli, malaria, and tuberculosis, will kill more people per year than cancer. The Review on Antimicrobial Resistance also found that drug resistance will cost up to $100 trillion annually by 2050 and cause 10 million deaths per year if no actions are taken to curb overuse of antibiotics, especially in livestock farming.



» ElectRx

DARPA has invested $79 million in the Electrical Prescriptions (ElectRx) program, which aims to create new biomedical interventions that improve mental and physical health through targeted stimulation of the peripheral nervous system. DARPA's effort is part of a growing interest in "electroceuticals", which could lead to treatments that accelerate the body's natural healing capabilities.

» Surgical Stem Cells

Two independent teams of scientists in the United States and Japan have developed new surgical techniques that use stem cells to replace eye tissues damaged by cataracts and other ocular conditions. Ultimately, this research may eliminate the need for cataract surgery and other invasive treatments.

IMPACT

» Social

Society will largely benefit from healthier, more active populations, but there will be rising tensions over access to costly medical interventions. As medical treatment enables more senior citizens stay in the workforce, there could be increased competition with younger workers for jobs and new challenges for educational and public welfare systems.

» Political

Access to life-saving medical technology will place significant stress on health care systems around the world, leading to difficult political decisions about health care financing, patent protection for pharmaceuticals, and the legal limits of medical intervention.

» Economic

Workers will remain productive well into their 70s and even 80s. Genomics and biomedical engineering will grow into enormous industries that need millions of educated workers.

» Environmental

Environmental impacts of future medicine are unclear, though rising populations will create more waste and create challenges for sustaining larger populations that will increasingly enter on growing cities.

» Defense

Regenerative medicine and other breakthroughs will transform battlefield medicine, extending the golden hour and allowing troops to recover from injuries faster. Genetic therapy will mean that recruits who come to the services with congenital or developmental problems can be "fixed" to meet accession standards.

A combination of nano-, bio- and information-technology will revolutionize healthcare. However, delivering high-tech, personalized forms of treatment while ensuring universal access to healthcare may create budgetary strains when shaping future health policy.

— European Strategy and Policy Analysis System

Coupling advances in biotechnology with other emerging technologies, such as nanotechnology, will produce even further advancements. In the future, it will be possible to implant "microscopic robots in your circulatory system that keep track of your blood pressure, detect nascent heart disease and identify early-stage cancer.

— Center for Strategic and International Studies

MOBILE AND CLOUD

Mobile and cloud computing are transforming the way people interact with data. In the United States, an estimated 30 percent of Web browsing and 40 percent of social media use are currently done on mobile devices. By 2030, 75% of the world's population will have mobile connectivity and 60% should have broadband access. Mobile devices are becoming more powerful and feature-rich, with a growing variety of embedded sensors that measure weather, location, ambient light and sound, and biometrics. Working in tandem with mobile data access, cloud computing provides access to almost unlimited computational power that scales seamlessly without requiring massive investments in IT infrastructure. Over the next 30 years, cloud-based mobile computing has the potential to transform everything from health care to education. Cell phones will monitor vital signs and communicate directly with diagnostic applications, people will use online educational portals from mobile devices to learn new skills, and apps will allow farmers in developing nations to connect to real-time weather data and tools for optimizing their harvests. At the same time, mobile and cloud computing will put significant pressure on network security, reliability, and bandwidth.

36.67%
CONCURRENCE

3.81%
SHARE

ENABLING S&T

» Robust wireless networking

Secure, reliable, high-bandwidth wireless networks are the lifeblood of mobile, cloud-based computing. With data traffic on mobile devices growing at 80-100% over the past several years, innovation in spectrum management and data protocols will be critical for nurturing accelerating growth in mobile and cloud solutions.

» Near-field & low-power networking

Near-field communications through low-power radio signals is beginning to be used in mobile payment systems that let consumers purchase goods using their cell phones. Low-power networks for networking wearable devices will also be important as smart watches, activity monitors, and other devices join the personal data ecosystem.

» Power and energy

Power is emerging as a limiting factor in mobile device performance. Since 2000, battery capacity has only doubled, while processing speed has increased 12-fold. Breakthroughs might occur in alternative chemistry batteries or wireless charging, but mobile technology developers are also working on optimizing power management.

SIGNALS

» Data Mobility

Intel is collaborating with startups CoreOS and Mirantis Inc. to develop ways to empower companies to move computing jobs between competing cloud services, or between their own data centers and cloud-based ecosystems. This collaboration targets growing concern among businesses over loss of data ownership and enterprise agility resulting from vendor lock-in.

» Mobile Malware on the Rise

A recent Mobile Threat Intelligence report from threat defense company Skycure found that more than 27 million Android devices running medical apps are likely to have high risk malware installed. Given that 80 percent of doctors use mobile devices in their practice, and 28 percent store patient data on their mobile device, mobile medical data is a prime target for cyber criminals.

» Mobile Processors for the Cloud

Cloud computing is driving innovation in computer processor design. Intel recently released its Xeon E5-2600 chip, which boasts 22 processing cores and runs 28% faster than previous generation processors. The chip also draws 145 watts of power and generates a lot of heat, pointing to the power management challenges that go hand in hand with the growth of cloud computing.

IMPACT

» Social

Mobile computing will transform the way people access information, opening the doors to education and productivity tools for millions of people living in both the developed and developing world.

» Political

As mobile and cloud solutions dominate more aspects of work, education, health, and daily life, governments will have to grapple with privacy, data ownership, consumer protections, cybersecurity, and demands for expanded spectrum and wireless infrastructure.

» Economic

The annual economic impact of mobile and cloud computing could reach $5-16 trillion by 2025, with significant growth in the developing world.

» Environmental

Growth in mobile computing over the next 30 years will come with large increases in demand for power for charging mobile devices and sustaining massive (and energy-hungry) data centers. Increased mobile ownership will lead to more mining to supply the raw materials needed for manufacturing these devices. Batteries and other mobile device components contain toxic materials, making safe disposal of old and broken devices a significant environmental challenge.

» Defense

As mobile computing continues to grow, wireless networks and cloud-based data will become prime targets for terrorists and trans-national criminal organizations. As defense resources continue to decline, cloud-based computing might offer significant cost savings for the Army, if security can be maintained. Mobile applications will become a primary avenue for recruiting, training, and communication among U.S. forces..

In just a few years, Internet-enabled portable devices have gone from a luxury for a few to a way of life for more than one billion people who own smartphones and tablets. Ubiquitous connectivity and an explosive proliferation of apps are enabling users to go about their daily routines with new ways of knowing, perceiving, and even interacting with the physical world.

— MGI

Vast numbers of people in developing countries will gain access to the web, thanks to a combination of plummeting costs and exponential improvements in technology. This will include laptops, tablets and smartphones that can be bought for only a few tens of dollars, together with explosive growth in the use of mobile broadband. Even some of the most remote populations on Earth will gain access to the Internet.

— Global Futures and Foresight

QUANTUM

23.33%
CONCURRENCE

2.54%
SHARE

Quantum computing uses properties of subatomic particles like superposition and entanglement to represent and manipulate data. While the technology has been discussed as a theoretical possibility for decades, recent research efforts across academia, industry, and government labs are beginning to demonstrate quantum systems that might have practical applications in the next 5-15 years. Quantum computing could be a linchpin technology that revolutionizes multiple other technical domains such as climate modeling, pharmaceutical research, and materials science. Quantum computing could also revolutionize cryptography. A quantum computer could crack all current encryption methods, and quantum cryptography could provide the first truly unbreakable encoding technology. Recent research has begun to overcome many of the technical problems that have limited the development of practical quantum computers. While real-world applications of quantum computing might not be seen until the mid-2040s, an influx of investment by governments and industry signals that quantum computing might be approaching a tipping point.

ENABLING S&T

» Quantum Error Connection

The fundamental unit of computation in a quantum computer is the qubit, which stores information in the quantum state of electrons. These states are extremely fragile, and tend to "decohere", resulting in data loss. The field of quantum error correction examines how to stave off decoherence and other errors.

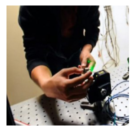
» Quantum Programming

Quantum computers create output that is probabilistic, not concrete. This means a calculation must be repeated many times before a stable answer emerges. Programming this kind of system is very different than working with traditional computers, and development of quantum programming methods is an active area of research.

» Post-Quantum Cryptography

Through 2040, quantum encryption will likely be a niche capability used to secure a limited range of especially sensitive information. The vast majority of networked systems will still use traditional encryption methods that will be increasingly vulnerable to hackers using increasingly capable quantum computers. This emerging risk has led the National Institute of Standards and Technology to push for investment into "quantum resilient" systems.

SIGNALS

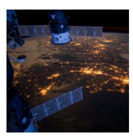


» Preserving Superposition

Researchers at the Massachusetts Institute of Technology (MIT) have developed a new technique for preserving quantum superposition using a class of devices made from synthetic diamonds. While still in the early stages of research and development, this technology could solve the decoherence problem.

» IBM Puts Quantum in the Cloud

IBM has made its five-qubit quantum research computer available for anyone to use through an online service. So far, over 26,000 people have run over 150,000 programs through the IBM Quantum Experience web portal.



» Quantum State Preserved in Space

A team of Italian scientists have demonstrated that photons sent through space and back to Earth can maintain their quantum state. This discovery could contribute to the development of quantum-encrypted satellite communications.

IMPACT

» Social

Quantum computers will enable rapid calculations on massive data sets that are impossible today. This could affect medical research, enhance big data analytics, and protect individuals and societies from cybercrime.

» Political

The ability of quantum computers to crack commercial encryption will lead to significant political concerns over privacy and cybersecurity. Bank accounts, email, and any other data not secured using quantum cryptography will be open to cyberattack.

» Economic

Economic impacts of quantum computing will be felt in financial modeling, logistics, engineering, health care, and telecommunications. Quantum computers would solve analysis problems within seconds that currently require days of supercomputing time.

» Environmental

The massive processing power of quantum computers would revolutionize climate modeling and lead to far more accurate forecasts of weather and climate change.

» Defense

Quantum cryptography will transform information security and signals intelligence. Adversaries using quantum computers would be able to crack traditionally encrypted systems used by the U.S. or our allies.

Indeed, some experts believe that quantum computing may make all codes 'crackable' and genuine encryption impossible, as theoretically a quantum computer could try every possible combination of codes simultaneously to unlock a system. If this is the case, armed and security forces may have to physically separate their computer systems from the Internet, posing huge problems for networking and efficiency.

— UK Ministry of Defense

Quantum computing represents a potentially transformative alternative to digital computers, but the breadth of its applicability and impact remain unclear and the time frame for commercialization is uncertain.

— McKinsey Global Initiative

SOCIAL EMPOWERMENT

53.33%
CONCURRENCE

10.39%
SHARE

Approximately 65% of American adults now use social media—up from 7% in 2005. Social media has undoubtedly changed the way people connect online, but over the next 30 years, social technologies will become an engine for empowering individuals to shape their own micro-cultures. Many traditional power structures will be overturned as people form Internet-based communities defined by technologically-mediated social contracts. Governments will find it increasingly difficult to control the political narrative as people share eyewitness accounts of corruption and oppression directly, without the filter of mass media.

While corporations will learn new techniques for engaging with consumers through social channels, those same consumers will use social platforms to cut through advertising noise and hold businesses accountable for their products and actions. Crowdsourcing and content streaming will further democratize content creation and blur the lines between media creators and consumers. Bitcoin and other cryptocurrencies could lead to definitions of currency and trade based on social consensus rather than government control. For the U.S. Army, social empowerment will radically change how young people view national service.

ENABLING S&T

» Blockchain
Blockchain is a distributed ledger technology that shares a complete record of every transaction that has occurred within a network with every member of that network. Changes to the ledger require consensus of a majority of the members, and, once entered, information can never be erased. Blockchain currently powers Bitcoin, but its robust, decentralized approach to managing trust and privacy in online transactions is gaining traction in other applications, including social networking and online voting.

» Applied Social Science
Decades of research in anthropology, social psychology, and political science have yet to be applied to the design of social networks. Future networks will leverage social science to build more vibrant and empowering communities.

» Identity & Reputation Management
Social media data has an indefinite lifespan. Employers already scan prospective hires' social network accounts, and online behavior could increasingly influence a person's real-world prospects. As social platforms come of age there will be growing demand for technologies that can help people manage –and in some cases repair–their online reputations.

SIGNALS

» Blockchain Goes Corporate
A growing number of financial institutions are experimenting with blockchain, including the New York Stock Exchange, Nasdaq, the London Stock Exchange, and Visa.

» Social Media and Mental Health
A pair of recent studies out of the University of Pittsburgh have examined potential health consequences of excessive social media use. One of the studies found that people who spent more than an hour a day on social media were 2.7 times more likely to experience depression. The other study linked excessive social media use with sleep disturbances.

» Internet Saathi
Google India's digital educative initiative, Internet Saathi, is helping connect women in rural India with web-based education and training resources. Since the launch of this initiative, Google India has directly trained over 1.5 million women on the basics of the internet.

IMPACT

» Social
As web-mediated social communities become more immersive they will become woven into our lives. Social bonds may migrate online, and traditional connections based on nationality may fade in importance.

» Political
Government surveillance on social networks will likely increase as social media becomes a more prevalent platform for political activism and protest.

» Economic
Crowdsourced products and content will continue to evolve to satisfy economic and entertainment niches. At the same time, corporations will continue to use social channels to engage with consumers, with varying degrees of success.

» Environmental
The environmental impacts of social technology are unclear, but it is likely that many social networks will emerge with an environmental focus, organizing distributed and decentralized environmental action.

» Defense
Terrorists and criminal organization already use social networks to share information and coordinate attacks against the US and its allies. As social networks begin to support virtual telepresence and self-contained economies the power of hostile networks could grow.

Tools like blogs, forums, Facebook, and Twitter are shifting the power balance from company to consumer. It allows users to compare prices, review products and voice their opinions. Consumers have always had a voice, but now it's louder and it spreads quickly because of social media. This generation of consumers is versed in harnessing the power and energy of the individual to make meaningful changes.

— Australian Department of Defense

Around the world from Brazil to Singapore from South Africa to the United Kingdom so-called social stock exchanges are already disrupting both traditional corporations and philanthropies while bringing financial vigor to new kinds of enterprises that focus on social and environmental impact. And as social media signals become a source of "market intelligence" for algorithmic trading they could catalyze an accidental--or intentional--market crash.

— Institute for the Future

SYNTHETIC BIOLOGY

30.00%
CONCURRENCE

2.12%
SHARE

Humans have manipulated the genetic code of plants and animals through selective breeding and hybridization for millennia – well before Mendel identified the basic laws of heredity or the Avery-MacLeod-McCarty experiment identified DNA as the genetic material. However, as our understanding of genetics has grown it is becoming possible to engineer custom organisms by building new sequences of DNA from scratch. Genetically-modified crops represent the vanguard of this technology, but we are on the cusp of a broader revolution that will turn life itself into information that can be written and rewritten much like computer code. Scientists are already engineering algae that can secrete biofuels and using DNA to encode thousands of gigabytes of data. Over the next 30 years, synthetic biology will give rise to engineered organisms that can detect toxins, create biofuels from industrial waste, and deliver medicine through symbiosis with human hosts. At the same time, synthetic biology represents profound risks, including engineered biological weapons and invasive synthetic organisms that could destroy natural ecosystems.

ENABLING S&T

» Modeling and Simulation

Synthetic biology will benefit from better modeling and simulation of of biochemical reactions, how proteins with desired functional properties can be created through engineered DNA, and of interactions among the components of complex synthetic biological systems.

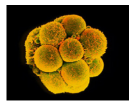
» Standardized DNA

Standardized DNA "biobricks" are accelerating research and development of synthetic organisms by providing scientists with reliable, well-understood foundations for genetic experimentation. The BioBricks Foundation, an international nonprofit agency, maintains standards for genetic components that are used to design and assemble larger synthetic biological circuits that can be incorporated into living cells, creating new biological systems.

» DNA Synthesis and Sequencing

Technologies like clustered regularly interspaced short palindromic repeats (CRISPR) are giving scientists much greater control over gene sequence editing, and emerging technologies are greatly lowering the cost and time associated with sequencing new copies of DNA.

SIGNALS

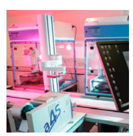


» Editing Embryos

Researchers in China have reported editing the genes of human embryos to try to make them resistant to HIV infection. This work builds on controversial research announced last year, in which Chinese scientists edited the genome of non-viable embryos to eliminate a gene responsible for a rare blood disorder. While both studies used non-viable embryos, the research has sparked an international debate over the ethics of human gene editing.

» Genetic Programming

Researchers from MIT, Boston University, and NIST have developed a technique for automating the design of synthetic genetic circuits. In essence, this technology forms the basis for a genetic programming language that could greatly accelerate progress in engineering synthetic organisms.



» Industrial-Scale Synthetic Bio

Scientists at Imperial College London have launched the Foundry, a $2.8-million-dollar facility that aims to industrialize the process of preparing DNA for synthetic biology applications. The lab uses robot automation to run thousands of genetic experiments simultaneously and should speed up progress in bringing synthetic biology applications to market.

IMPACT

» Social

Synthetic organisms will become part of our everyday lives, generating fuel for our cars, keeping our homes clean, and helping us stay healthy through engineered biopharmaceuticals. At the same time, concerns over "playing God" and fears about genetically-engineered superbugs could lead to calls for bans on certain applications of synthetic biology.

» Political

Regulation of synthetic biology is still in its infancy, and very few nations have laws on the books governing research and development of synthetic organisms. Governments could struggle to balance societal and economic benefits of synthetic biology with environmental and other risks.

» Economic

Synthetic organisms could generate inexpensive biofuels, improve industrial processes, and be tailored to deliver medicines through inoculation of human patients. The combined economic impact of these and other applications could be well over $1 trillion per year by 2045.

» Environmental

Invasive synthetic organisms that escape from labs or industrial facilities could devastate natural habitats, destroy crops, and contaminate water supplies worldwide.

» Defense

The Army could benefit from biofuels and biosensors made from genetically engineered organisms. At the same time, future adversaries could develop synthetic biological weapons that are highly lethal, communicable, and difficult to detect.

Recently, a deeper understanding of genomics, coupled with computational biology, is leading to the ability to hack life itself and build organisms that never existed in nature. From microbial factories that produce anti-malaria and cancer-fighting drugs to bugs that glow red in the presence of environmental contaminants and digest the toxins, synthetic biology points toward a future teeming with programmable life-forms built to do our bidding.

— Institute for the Future

In the new synthetic biology age, you will be able to edit DNA like software in a computer. Perhaps even more astounding than the ability to digitize life is that this digital life can be transmitted over the Internet and the organism recreated anywhere on the planet. Or, digital life can be used to recreate organisms found on Mars by digitizing their DNA and transmitting the file back to Earth.

— Atlantic Council

ADVANCED DIGITAL

40.00% CONCURRENCE

4.45% SHARE

Computers and other digital devices have transformed life so completely over the past 60 years that it is almost impossible to remember that these technologies are relatively new. The first personal computers weren't sold until 1975, and were only available as kits that customers had to assemble and program on their own. However, just 40 years later, 68% of Americans own smartphones that have more processing power than NASA did when it sent astronauts the moon in 1969. The next 30 years will likely continue the trajectory toward more computing power and wider availability of digital resources. Mobile and cloud computing will provide almost unlimited memory and processing speed. Virtualization and software-defined systems will allow governments and business to rapidly adapt IT infrastructure without costly and wasteful hardware upgrades. Digital will become integrated into an even wider array of everyday objects, from clothing to building materials. At the same time, technologies are emerging that will transform how we interact with our devices. Voice interfaces are already commonplace in smartphones, and will continue to improve. Gestural interfaces will allow us to communicate with computers through nonverbal behavior.

ENABLING S&T

» Apps, APIs, and Software-Defined Everything

Following trends in consumer software, enterprises are moving from applications to apps. As organizations push for greater agility a shift is underway toward simpler, more modular apps. Mirroring this trend toward modularity, application programming interfaces (APIs) are providing building blocks that greatly accelerate app development.

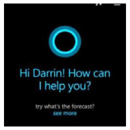
» Natural User Interfaces (NUIs)

NUIs greatly reduce the learning curve associated with new technologies and enable technologies to feel like a natural extension of a user's intentions. One example of an emerging NUI technology is the reality-based interface (RBI). One example of an RBI strategy is to use a wearable computer with a camera and computer vision software to render real-world objects "clickable", enabling users to interact with digital information by touching, picking up, and otherwise manipulating physical objects.

» Brain-Computer Interfaces (BCIs)

Brain-computer interfaces allow users to control digital systems directly through thought. Though most current research on BCIs is focused on clinical applications for people suffering from paralysis and other movement disorders, BCIs could one day become more commonplace, greatly expanding opportunities for interfacing humans and technologies.

SIGNALS



» Voice-Responsive Bots

Microsoft is exploring the concept of "conversation as a platform" - a collection of technologies that would allow users to converse with their computers and other digital devices via smart, voice-responsive "bots".

» Neuroverse

La Jolla-based startup Neuroverse is developing the Brainstorm - the first consumer-grade brain-computer interface. The Brainstorm uses novel, flexible EEG sensors to detect electrical signals generated by the brain. Early applications could be in thought-controlled video games and improved cognitive training apps.

» Software-Defined Networking

The global market for software-defined networking is expected to reach $56.1 billion by 2020, up from just $2.4 billion in 2015 - increasing at an impressive compounded annual growth rate (CAGR) of 88.1%.

IMPACT

» Social

Advanced digital systems will contribute to the growth of social media and power new applications in the home and business automation market.

» Political

As advanced digital systems spread throughout the private sector, the gap between public and private sector IT capabilities will continue to widen. Governments will face challenges as legacy computing systems become more expensive to maintain and less capable of interfacing with new technologies powering the global economy.

» Economic

Advanced digital technologies represent enormous new business opportunities across multiple markets, from business services to consumer mobile platforms. As these systems mature there will be massive opportunities for innovation and value creation.

» Environmental

It is unclear whether advanced digital systems will have an environmental impact, though software-defined services might enable optimization options that improve energy efficiency and reduce waste from outmoded electronics.

» Defense

Advanced digital systems could strengthen the Army's information and communications backbone, though there will be significant challenges integrating these systems into legacy devices. New human-system interface options could enable Soldiers to control robots and other technologies through conversation, gesture, and potentially thought. This could lead to a reduction in training requirements and more efficient mission performance.

Multiple computing device-level technologies, including tunnel field effect transistors (FETs), carbon nanotubes, superconductors and fundamentally new approaches, such as quantum computing and brain-inspired computing are expected in the future, rather than one dominant architecture.

— NATO

Those companies ill-equipped with state-of-the-art digital technologies or with outdated capacities may just be cut off from global markets, with dramatic consequences for the less connected and agile. At the same time, a new digital divide may result from uneven infrastructure coverage, locking certain areas and regions out of full access to the digital society.

— European Strategy and Policy Analysis System

BLENDED REALITY

26.67%
CONCURRENCE

3.39%
SHARE

Virtual and augmented reality (VR and AR) have been generating a lot of enthusiasm within the consumer electronics industry. Major electronics companies, including Samsung, Sony, and HTC are all releasing virtual reality products this year, signaling a major breakout of VR as a mainstream entertainment technology. Applications are emerging outside of entertainment. For example, the home improvement chain Lowes is developing the Holoroom - a 3D augmented reality room that allows shoppers to design a living area and then walk into a virtual model of the space to get a better feel for how it will look. While VR and AR have a history of overinflated expectations - VR was expected to revolutionize media in the 1990s – the combination of ultra high-resolution displays, low-cost position and location tracking, and high definition video content has laid a solid foundation for "blended reality" technologies that merge the real world with digital information. Over the next 30 years these technologies should become more prevalent. AR displays will deliver real-time, context-aware data overlays, and VR will enable deeply immersive experiences integrating sight, sound, smell, and touch. For the U.S. Army, VR and AR have applications from training to combat operations. For example, maintenance personnel will be able to visualize diagnostic data and repair routines through AR overlays that project information directly onto physical equipment.

ENABLING S&T

» Consumer-Grade Hardware

In the past two years a number of major consumer electronics companies have entered the virtual reality market. Industry research and development is focused on building low-latency, high definition displays at a consumer-friendly price. Despite Google's decision to pull back on its Glass augmented reality system following poor reviews and concerns about privacy, a number of companies, including Facebook, are investing heavily in AR displays integrated into eyewear.

» Blended Experiences

The goal of VR and AR technologies is to create compelling, multisensory experiences that seamlessly blend the virtual and physical world. Reaching this goal will require converging research in computer graphics, wireless motion tracking, computer vision, and human perception.

» Interaction Techniques

Blended reality is not a passive experience - it assumes users have the ability to interact with digitally-constructed objects and information. New methods of interactions, including gestural interfaces and reality-based user interfaces, are currently being developed that should allow us to act within virtual and augmented spaces just as we do in the real world.

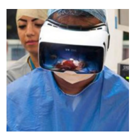
SIGNALS

» Cardboard HMDs

Since June of 2014, Google has shipped 2 million of its Google Cardboard head-mounted displays (HMDs). Cardboard HMDs - which are available for as little as $15 - are designed to turn any smartphone into a VR display, complete with 3D stereoscopic viewing. For dedicated makers, Google makes plans for building a Cardboard HMD freely available on the project's website.

» Blended Reality Market Forecast

Goldman Sachs has estimated that the global market for blended reality will reach $80 billion by 2025, with $45 billion in revenues from hardware sales and $35 billion from software.



» Live-Streamed Surgery

A team of doctors in the U.K. recently live-streamed an operation in virtual reality. While the stream wasn't strictly a VR experience (it was filmed with a 360-degree camera, and viewers could not move or interact within the environment) it points to emerging applications of VR in medical training and telehealth.

IMPACT

» Social

Blended reality will open new channels for people to travel (virtually) and engage with different cultures. At the same time, increasingly immersive experiences could become more attractive than the real world for many people, potentially fueling addiction and withdrawal, similar to the epidemic of online gaming addiction currently plaguing Japan.

» Political

Blended reality technologies will almost certainly include cameras and be networked, leading to new concerns over privacy, identity theft, and state surveillance. Governments may come under pressure to regulate virtual and augmented reality to protect individuals, businesses, and public agencies from blended reality-based violations.

» Economic

As indicated above, the global market for blended reality technologies is potentially very large. Capital flows into this sector are accelerating, with $3.5 billion in venture capital investment in the last two years alone.

» Environmental

Blended reality might have an indirect effect on environmental awareness by making virtual eco-tourism and immersive environmental educational more widely available.

» Defense

The U.S., U.K., and other nations have invested in virtual and augmented reality technologies for decades. In the past, technical limitations have prevented blended reality from being practical outside of training environments and other limited applications. However, with commercial innovation rapidly improving both hardware and software it is possible that the Army will be able to deploy VR and AR systems to the battlefield, revolutionizing how Soldiers access information and conduct operations..

Long the objects of sci-fi fascination, the looming potential of AR and VR technologies lies in the enterprise with capabilities that could potentially reshape business processes, or fundamentally recast customer experiences. While the consumer world waits for the dominant AR and VR players to emerge, the enterprise can fast-track adoption—and begin the process of fundamentally reimagining how work gets done.

— Deloitte

Emerging technologies will be able to create near realistic battlefield conditions at each command echelon. Extended battles in next generation training will involve every aspect of the force structure. An integrated exercise will test maintenance crews, logisticians, intelligence feeds, and other reachback support. If a logistician delivers an iron mountain to the exercise, then a participant has to get it to the warfighter-whether the bullets are at the bottom of the pile or the top.

— Defense Science Board