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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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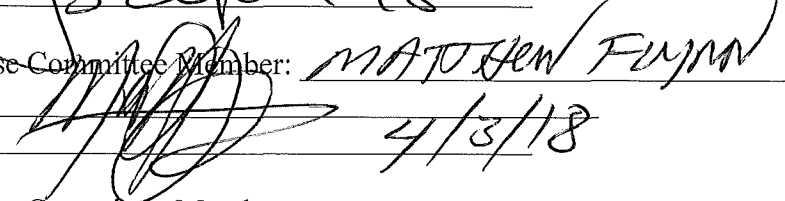
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Preface

Based on my previous experiences in a US Marine Corps Low Altitude Air Defense (LAAD) Battalion and as a Marine Aviation Command, Control, and Communications Weapons and Tactics Instructor, I have benefited from numerous advanced technologies. These technologies range from next-generation radar systems, autonomous unmanned aerial vehicles, advanced command and control platforms, directed energy weapon system prototypes, cutting-edge mission planning software, and secured data and communications system networks. The benefits of each of these systems have increased the decision-making process of commanders, reduced fratricide, enhanced situational awareness, improved the efficiency of resource allocation, and maximized the lethality of the US Marine Corps. Additionally, many of these systems and the capabilities they provide were unimaginable just twenty years ago.

Technological advancements will influence every single aspect of warfare in the future. I believe that in the very near future, individual commanders will find themselves single-handedly fighting a simultaneous, multi-domain battle. Naturally, this type of warfare can present a whole slew of potential problems, present complex decision-making scenarios, and ultimately hinder or restrict operations. My goal is to present an overview of rapidly evolving technology trends to decision makers in the US Marine Corps and bring to light the potential positive and negative impacts on the future operating environment. My research would not have been complete without substantial input from the Marines within the LAAD and aviation command and control communities. I would also like to thank my mentor, Doctor John Gordon, and my faculty advisors Lieutenant Colonel Ronald Rega, and Doctor Francis Marlo for their continued support and guidance.

Executive Summary

Author: Major Robert M. Barclay, United States Marine Corps

Thesis: To fight a simultaneous multi-domain battle in the future, US Marine Corps leaders need to prepare for the impact of the internet of things, artificial intelligence, human enhancement and augmentation, and additive manufacturing, and be ready to leverage and employ or defend against these capabilities.

Discussion: Numerous reports predict that the growth of technology is expected to continue at an exponential rate. The commercial market growth of technology, in almost every industry, is a clear indication of this trend. The most significant and ground-breaking advancements have occurred in the top four technological trends: the internet of things; artificial intelligence; human enhancement and augmentation; and additive manufacturing. These technologies possess revolutionary potential in their future application across all five domains. These technologies present both substantial benefits and considerable risks. The US Marine Corps's ability to leverage these technologies, along with protecting its networks, systems, weapons, and equipment will be the key to success in the future operating environment.

The future operating environment will be full of complexity and uncertainty. The US is the primary focus of adversaries, as the US's focus has been counter-insurgency operations in the Middle East since the onset of the Global War on Terror. Nevertheless, the US Marine Corps will be expected to succeed anywhere it is called to do so. The current arsenal of technology, weaponry, systems, and equipment possessed by the US Marine Corps does not guarantee victory in the next significant conflict. The US Marine Corps must continue to remain as flexible and adaptable as possible; it must also continue to innovate across the force while modernizing the service as quickly and efficiently as possible. All Marines must be prepared to leverage and employ or defend against these evolving technologies on the future battlefield.

Conclusion: Technology will continue to grow at an exponential rate across all industries and markets for the foreseeable future. The internet of things will continue to expand and impact every facet of human life. Artificial intelligence possesses potentially incredible capabilities in its application. Human enhancement and augmentation will continue to be explored and implemented globally, while moral and ethical concerns fall by the wayside. Additive manufacturing advancements will continue to challenge the traditional manufacturing process and the current legacy supply chain system. The US Marine Corps needs to continue to open its aperture and take the necessary steps to explore these technologies and prepare both for their positive and negative impacts on operations. For the US Marine Corps, sound leadership, flexibility, adaptability, and readiness will continue to be essential. The nation is counting on the US Marine Corps to "fight and win" on the future battlefield, regardless where that may be, and these technologies can help facilitate that success.

Introduction

“New commercial technology will change society and, ultimately, the character of war.”
- Secretary of Defense James N. Mattis

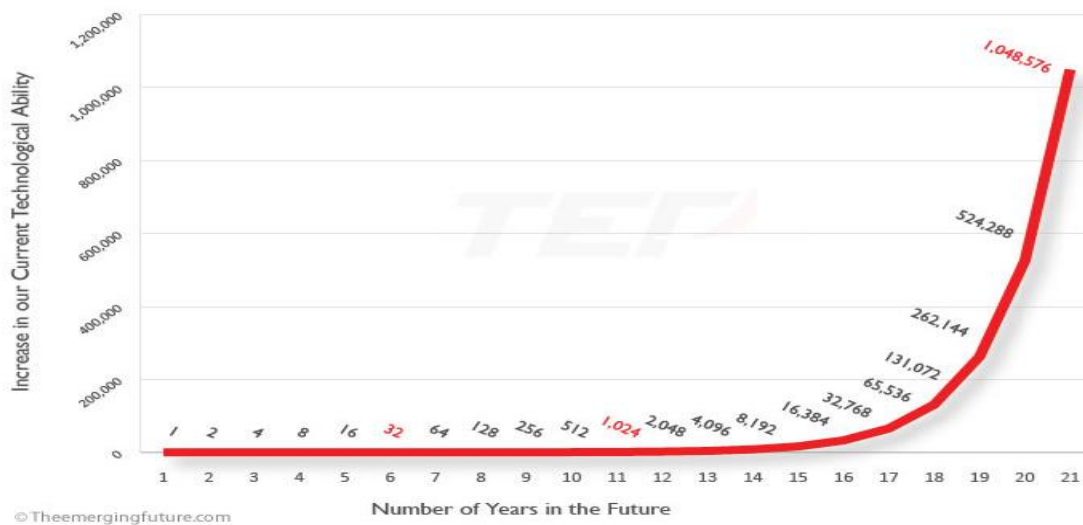
In 1983, the digital revolution hit its stride with the creation of the internet. Since the public introduction of the World Wide Web in 1990, the world has witnessed astronomical advancements in technology that impact, and will continue to impact, every facet of human life. If the previous two decades are any indication of the future, and in particular technology’s impact on the conduct of war, the world is in for extraordinary technological innovations and advancements. Conversely, it is difficult to imagine that the growth of technological advancements and the clash with both external and internal threats will decline. Technological innovation is continually shaping the exceedingly uncertain and complex future operating environment, presenting a problem that needs to be confronted by the US Marine Corps when it fights on the multi-domain battlefield. The multi-domain battlefield is best defined as an area of operations in which kinetic and non-kinetic actions are employed simultaneously, across domains, under the purview of a single commander.¹ To fight a simultaneous multi-domain battle in the future, US Marine Corps leaders need to prepare for the impact of the internet of things, artificial intelligence, human enhancement and augmentation, and additive manufacturing, and be ready to leverage and employ or defend against these capabilities.

Technology and weaponry to conduct war are becoming more increasingly connected, lethal, and accessible. As an example, for the US military, the acquisition and adjudication of targets can now occur at the speed of light, across multiple domains, using next-generation optics and directed energy weapon systems. In *Future War*, Latiff states, “Sadly, the period has also seen monstrously destructive wars and a seemingly

never-ending proliferation of arms and violence around the world. These two developments—technological advancements and destructiveness in war—are now more co-dependent than ever before.”² The application of violence through highly advanced weaponry has the potential to bring about more destructive results and will most surely challenge the moral and ethical fabrics of society. Technological advancements are fundamentally changing the character of warfare, and future success on the battlefield depends on the ability for the US Marine Corps’ to adapt to these emerging technologies to the American way of war. As in the past, the connection between technology and the application of warfare will undoubtedly continue and become more increasingly relevant.

Technology is virtually everywhere, proliferation is on the rise, and there are no indications of it slowing down. Technological advancement in its entirety continues to grow exponentially as depicted in figure 1, while the cost for many of these technologies remains relatively affordable for the average consumer.

Figure 1: The Growth of Technological Advancements in Twenty Years



Source: The Emerging Future’s Article on Estimating the Speed of Exponential Technological Advancement, <http://theemergingfuture.com/speed-technological-advancement.htm>.

A cell phone, for example, is now in the hands of almost every person on earth and serves as a gateway to an infinite information database through worldwide interconnectivity at a reasonably affordable price. Technological proliferation also continues to expand at an extraordinary rate, while increasingly penetrating and influencing everyday life.³ For example, in home products like Amazon's Echo, Google's Home, and Apple's HomePod are advanced technologies with a wide array of applications and are increasingly growing in popularity. Almost every piece of technological equipment is now more connected, intuitive, and aware.

Additionally, many people can quickly access their bank accounts, medical records, family history, vehicles, businesses, homes, and buildings via an electronic device. Facial recognition software, fingerprints, radio frequency identification chips (RFID), electronic keys, and passwords provide electronic access and are increasingly essential aspects of daily life. Conversely, criminals, terrorist organizations, nation states, and hybrid threats routinely compromise these technologies and their networks to exploit vulnerabilities for a variety of reasons. Technology provides these threats the ability to conduct cyber-attacks to impact decision making, acquire sensitive items and information, monitor activity, or destroy/disrupt operations. The current overarching plan from the US Department of Defense (DoD) to counter these emerging threats lies in the Third Offset Strategy.⁴

An offset strategy is a set of competitive strategic policies designed to generate and sustain advantages over adversaries.⁵ The Third Offset Strategy is the most recent offset strategy, which focuses on the resident technological innovations in the US. There are few elements to the Third Offset Strategy: The first focuses on deep-learning systems, which would be able to analyze thousands of pieces of information almost

instantaneously. The second element is human-machine collaboration, which would enhance humans' ability to process information and increase decision making. The third is human-machine combat teaming, which focuses on autonomous systems electronically tethered to humans to enhance a person's ability to conduct operations. Assisted human operations is the fourth element, such as exoskeletons, wearable devices, and heads-up displays. Finally, the fifth element is network-enabled cyber-hardened weapons, which focuses on cybersecurity of weaponry in the future operating environment.⁶ For the US Marine Corps, technological advancements will be the most influential factor impacting future operations. The future operating environment is not only challenging to define but also inherently unpredictable, and that is precisely where the US Marine Corps will be expected to succeed.

There is one thing that is almost certain in the future operating environment, that it will be riddled with ambiguity and layered with complexity. Latiff states in *Future War*, "A new and frighteningly complex world of conflict and technology and the inevitable deadly dilemmas we will face in the twenty-first-century wars demand that we pay more attention to the issues that will confront us before it is too late to control them."⁷ Undoubtedly, the next two decades will introduce more challenging and complex problems that may be difficult to comprehend. The human element in the conduct of warfare has always been a constant, but continued technological advancements will challenge that paradigm. The US Marine Corps must prepare to meet these issues and challenges head-on while continuing to remain adaptable, forward-thinking, and on the cutting edge of these technologies.

The Internet of Things

"The only constant in the technology industry is change." - Marc Benioff

The first most significant and evolving technology trend that will impact the future operating environment is the ever-increasing internet of things (IoT). Simply stated, the IoT is an object that can connect to a network. The overall concept of connected and communicating things dates back to the late 1920s, but in 1999, Kevin Ashton coined the term IoT, as published in a *Forbes* magazine article in 2001.⁸ Since then, the development of connected objects and devices has skyrocketed. In 2017, there were an estimated 8.4 billion connected devices around the world.⁹ The use and potential modification of all of these connected devices are limited only by an individual's resourcefulness. All of these connected devices can sense, track, process, and share information to accomplish tasks.

The market for the development and application of IoT products is enormous. According to *Forbes* in 2016, products in 2025 that possess sensor-networking, processing, and analytical capabilities will reach 75.44 billion.¹⁰ *Forbes* also estimates that the market for IoT products and services will be 2.7-6.5 trillion USD until 2025.¹¹ The importance of IoT varies by industry, but it drives technological innovation, advancement, and development of a variety of goods and services, both in the US and abroad. Many experts believe the future of the IoT is the Smart City, where almost everything is connected, controlled, and monitored electronically. Currently, the global leader in the Smart City concept is the country of India. Smart Cities, like in India, can electronically monitor and control city energy consumption, water and air quality, surveillance, transportation, waste management, advertisements, and emergency service dispatching.¹² The global demand for connecting everything to enhance the quality of life, reduce inefficiencies, and maximize resources is remarkable.

The IoT continues to expand, and the demand for such connected products, both for commercial and personal use is staggering. In *The Inevitable*, author Kevin Kelly states, “The computer manufacturer Cisco estimates that there will be more than 50 billion devices on the internet by 2020, in addition to tens of billions of screens. The electronics industry expects a billion wearable devices in five years, including 13 billion appliances, 3 billion devices in cars, and 100 billion dumb RFID chips embedded into goods on the shelves at Walmart.”¹³ Many experts believe there will be over 100 billion connected devices by 2035. IoT is influencing the consumer market in every way imaginable. The world’s largest companies like Apple, Google, Amazon, Intel, Microsoft, and IBM are heavily investing in this type of technology, all seeking to capitalize on the rapid expansion of this technology trend. The US military has taken notice and is also significantly investing in this kind of technology.

The US military has become increasingly connected over the last two decades. The positive benefits from integrating the concept of IoT into the military are significant. For example, Nicholas Fearn states, “[The US Army has] already implemented a classified communications network line spanning 48,000 miles, which is being used for missile defense and battle coordination scenarios. This warfighting network merges elements of the Army's ballistic missile defense system into one central hub, which can be used to counteract threats all over the world.”¹⁴ The military’s need for accurate, timely, and detailed information continues to be insatiable. The myriad of information and data collection system in the form of radars, sensors, satellites, aircraft, ground troops, and vehicles has led to an increase in networking and data sharing capabilities across all military services. The military’s own IoT network is proving to be of incredible valuable thus far. The collection and sharing of information have become inextricably

linked to the development of military commanders' situational awareness, decision making, intelligence gathering, analysis, and targeting. In the future operating environment, the security, protection, and defense of these connected systems should be the primary concern for all military services, especially the US Marine Corps. In the future operating environment, anything that can be connected will be connected, which brings about some substantial challenges and potential security concerns.

US Marine Corps IoT networks that process, share, analyze, and distribute information also present a prime target to an adversary. The threat from cyber-attacks on behalf of state-sponsored adversaries is just one principal concern. For example, the US Marine Corps could find itself as a target of cyber ransomers in the future. Simply stated, cyber ransom is a directed cyber-attack that extorts its victim for financial gain. Pascaal Geenens, an EMEA security evangelist from Radware, states in an article on *The Internet of Business*, "One of our predictions for the year ahead is that cyber-ransomers will extend their reach beyond companies, and the armed forces could well find themselves the target of a ransom attack. Seemingly innocuous cameras, sensors, and other IoT devices pervade the military but are just as rife with security issues as any on the planet. Once demonstrable vulnerabilities are validated, how much would a government pay to regain control of weapons or other crucial resources?"¹⁵ Cyber-ransom is just one of the many vital concerns that connected technologies present. Cyber-attacks can shut down or stall entire systems, manipulate data, monitor activity, acquire information, or destroy critical infrastructure as demonstrated in 2007 during the Aurora Generator Test where a cyber-attack destroyed a large diesel generator. In the future, the protection and defense of these IoT networks will be critical to the US Marine Corps's success in the multi-domain battlespace of the future operating environment.

The US Marine Corps seemingly grasps the importance of protecting its IoT networks as outlined in the *Marine Operating Concept* published in September 2016 by stating, “Protect our networks and nodes as the friendly center of gravity.”¹⁶ However, the US Marine Corps needs to invest much more heavily in the Cyber Network Specialists (formally, Data Network Specialists) to ensure the protection and defense of its networks. The US Marine Corps should also seek to leverage commercial heavyweight technology companies that are outside of the military defense network, through a Marine liaison program, to greater enhance its understanding of its network defense capabilities and emerging threats. Cyber defense is especially important in the future operating environment as hybrid cyber threats continue to emerge from state actors, terrorist organizations, and cybercriminals.

The interconnectedness of IoT will continue to expand and evolve in all industries in the next two decades, from wearable or implanted devices to entire city power grids.¹⁷ The US military should continue to leverage these technologies to increase efficiency and effectiveness of the armed services; however, as the world trends to more interconnectedness, the defense of these networks and connected systems is essential. The US Marine Corps should invest heavily in cyber defense of its networks and leverage private industry through a robust liaison program, especially if the future connected networks and systems utilize “thinking” computer systems.

Artificial Intelligence

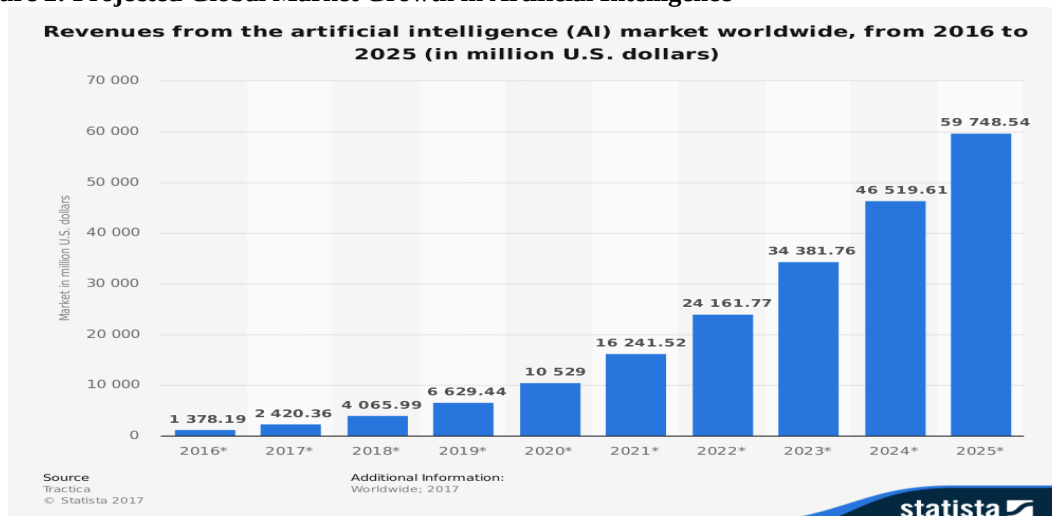
“The real problem is not whether machines think but whether men do.” - B.F. Skinner

The rapid development and evolution of Artificial Intelligence (AI) is the second most significant technology trend that will impact the future operating environment in the next twenty years. AI is simply the simulation of human intelligence by a machine, and it

will more than likely become the most powerful general-purpose technology over the next two decades. The continued evolution and advancements in AI will be the most substantial technological development in the next century. Kelley states in *The Inevitable*, “AI will help us better understand what we mean by intelligence in the first place...we haven’t just been redefining what we mean by AI—we’ve been redefining what it means to be human.”¹⁸ The idea of AI dates back thousands of years to Greek Mythology; however, in 4th century B.C., Aristotle invented syllogistic logic, the first deductive reasoning system.¹⁹ Since then, the most significant advancements in AI and machine learning (ML) had occurred following World War II, when modern computers became available.²⁰ The overall commercial investment, growth, and expansion of AI in recent years are substantial.

In 2016, virtually every major technology conglomerate invested in AI. Technology companies spent between \$26 to \$39 billion on AI in 2016, mostly in the area of research and development.²¹ The automotive, finance, high tech, and telecommunications industries are the most active digital adopters of AI.²² Outlined in figure 2 are the projections for AI market growth by 2025.

Figure 2: Projected Global Market Growth in Artificial Intelligence



Source: Money Control's Article on Projected Global Market Growth of AI,
<http://www.moneycontrol.com/news/business/data-story-next-investment-opportunity-artificial-intelligence-market-projected-to-grow-25-fold-in-eight-years-2411419.html>.

AI's global economic impact by 2025 is predicted to be substantial. Aditya Kaul, a research director at Tratica, states, "Artificial intelligence has applications and use cases in almost every industry vertical and is considered the next big technological shift, similar to past shifts like the industrial revolution, the computer age, and the smartphone revolution."²³ By 2035, if the curve of AI market growth stays on course as anticipated, AI is going to be utilized in every single industry, and militaries will be no exception.

The most remarkable advancements in AI in recent years are in the field of problem solving and cognition.²⁴ The most recent results from the application of AI systems are impressive. In a *Harvard Business Review* article titled, "The Business of Artificial Intelligence," Erik Brynjolfsson and Andrew McAfee highlight the most recent achievements in systems rooted in AI:

Machines have already beaten the finest (human) players of poker and Go — achievements that experts had predicted would take at least another decade. Google's DeepMind team has used ML systems to improve the cooling efficiency at data centers by more than 15%, even after they were optimized by human experts. Intelligent agents are being used by the cybersecurity company Deep Instinct to detect malware, and by PayPal to prevent money laundering. A system using IBM technology automates the claims process at an insurance company in Singapore, and a system from Lumidatum, a data science platform firm, offers timely advice to improve customer support. Dozens of companies are using ML to decide which trades to execute on Wall Street, and more and more credit decisions are made with its help. Amazon employs ML to optimize inventory and improve product recommendations to customers. Infinite Analytics developed one ML system to predict whether a user would click on a particular ad, improving online ad placement for a global consumer packaged goods company, and another to improve customers' search and discovery process at a Brazilian online retailer. The first system increased advertising return-on-investment threefold, and the second resulted in a \$125 million increase in annual revenue.²⁵

Currently, private industry and the commercial sector are leading in the field of AI and ML, both in research development and application. If AI can do all these things, it is

conceivable it can also enhance the abilities of commanders, troops, and pilots in the US military. In August 2017, DoD Secretary James Mattis toured Silicon Valley and mentioned, “[AI has] to be better integrated by the DoD because I see many of the greatest advances out here on the West Coast in private industry.”²⁶ The problem solving and cognition abilities provided by software and systems enhanced by AI can surely benefit the US military.

In the future, the US military could potentially find itself in a fiscally constrained environment where resources are limited. AI-enhanced software and systems can increase the overall efficiency and effectiveness of the military services, both in garrison and in combat.²⁷ As an example, AI-enhanced software and network systems can improve efficiencies in areas such as training, financial management, information management, resource management, communications networks, logistics, intelligence, supply, and maintenance. The effects of using AI can potentially minimize collateral damage, enhance decision making, reduce fratricide, extend the “golden hour,” and provide a more efficient medical care to personnel and their families. There are numerous possibilities for the use and application of AI-enhanced software and systems in the US military, but it does present some potential uncertainties.

AI can provide substantial positive benefits to the US military, but also presents a few causes for concern. The use of AI-enhanced software and systems is only beneficial if the raw data inputted is accurate. For example, the adverse alteration or modification of essential information and data that an AI system is analyzing could have potentially disastrous consequences. Furthermore, Robert Button, a senior operations research analyst at the RAND Corporation states, “Another is that it is still not ready for many tasks that require a deep level of contextual knowledge.”²⁸ As AI technologies continue

to evolve, many of these concerns will dissipate, but information and data will remain critically important to the US military, especially the US Marine Corps.

The never-ending thirst for accurate and timely information in the US Marine Corps reigns supreme. Whether commanders are dealing with an incident in garrison or during full-fledged combat operations, information, data, and intelligence drives operations and decision making. AI-enhanced software and systems can assist with decision making by managing relevant information, executing tasks, allocating resources, streamlining administration, and ultimately maximizing the efficiency of a unit.²⁹ The benefits of AI are comprehensive and are now just starting to emerge as the rapid evolution of this technology continues at an exponential rate. For the US Marine Corps to stay ahead of this technology trend, it should more intently research, embrace, acquire, and maximize the use of AI to increase effectiveness and service-wide understanding of its capabilities in preparation for the future.

AI's impact on the future operating environment will be significant. The growth of industries globally involved in the development and enhancement of AI systems is staggering.³⁰ The US Marine Corps can benefit from this technology in a variety of ways, across all domains, and through multiple applications. There will be no technology in the next twenty years that will be more influential to society or the military than AI-enhanced technologies. Additionally, the growing connection between AI systems and human beings will continue to expand, further fulfilling the innate desire for improving natural abilities and reducing limitations.

Human Enhancement and Augmentation

“Every assumption we hold, every claim, every assertion, every single one of them must be challenged.” - General Mark A. Milley

The melding of man and machine to enhance human performance is no longer only seen in science fiction. Human enhancement technologies (HET) and human augmentation is the third technology trend that will impact the future operating environment. Human enhancement refers to the general application of the convergence of biotechnology, information technology, nanotechnology, and cognitive science to improve human capabilities by enhancing performance.³¹ The fascination and desire for human enhancement is nothing new. The original concept or idea of human enhancement dates back thousands of years, presumably at the dawn of human civilization.

In the last century, the idea of enhanced humans has dominated the entertainment industry, spurring intrigue and curiosity amongst viewers. Many of the characters in books, comics, magazines, video games, television, and movies have been “enhanced” in one way or another. Many of the enhancements were either from internal and external biological or technological modifications. The definition of human enhancement is fairly well defined by bioethicist Eric Juengst when he states, “an enhancement is a medical or biological intervention to the body designed to improve performance, appearance, or capability besides what is necessary to achieve, sustain or restore health.”³² One essential element lacking from Juengst’s definition is the mention of technological intervention.

HET falls into two primary categories: biological and technological. The advancements in HET in private industry are advancing rapidly and for many obvious reasons. The most recent advancements in human enhancement and augmentation in the civilian sector have been remarkable, especially in the technological category. As an example, in July 2017, Apple and Cochlear, a hearing assistance company, co-released a device called the Nucleus 7. The Nucleus 7 is a device that connects a hearing impaired individual to an Apple iPhone via a surgically implanted sound processor that connects

by Bluetooth. The US Food and Drug Administration approved this device for widespread public use, which is a significant achievement.³³ Recent civilian industry growth, adoption, and approvals in HET are challenging the moral and ethical equation of human enhancement and augmentation.

The overall market growth for human enhancement in the next few years will be considerable. According to Laura Wood, “The human augmentation market is projected to witness a compound annual growth rate of 35.69% to reach a total market size of US \$2.546 billion by 2022, from the US \$0.544 billion in 2017.”³⁴ As an example, in July 2017 in Portland, Oregon, the scientists discovered a biological solution in human enhancement using genetic engineering. On July 26, 2017, *MIT Technology Review* published an article stating that a team of scientists from the Oregon Health and Science University, led by Shoukhrat Mitalipov, were able to successfully edit the DNA of a human embryo by using a technique called Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR). The CRISPR technique utilizes human genome editing technology, and the purpose of this ground-breaking scientific experiment was to correct deficiencies in human DNA that cause inherited diseases.³⁵ This scientific advancement is the first of many seeking to alter the natural course of human life. From a military perspective, the positive and negative consequences of this scientific and technological development will have a widespread impact on the future operating environment in the next twenty years.

The positive benefits of possessing the ability to modify and enhance the human genome are potentially limitless. The vast medical benefits alone would save countless human lives and could hypothetically increase the overall length of human life itself. By modifying the human genome, scientists could increase the current physical limitations of

the human body and considerably enhance overall physical performance.³⁶ The increases in physical performance, general reduction and elimination of medical concerns, and the extended life expectancy of the human being, among others, are worthy of lengthy discussion and debate. All of the potentially positive benefits of altering human DNA, and other biological human enhancement solutions, come with some significant concerns, especially from a moral and ethical perspective.

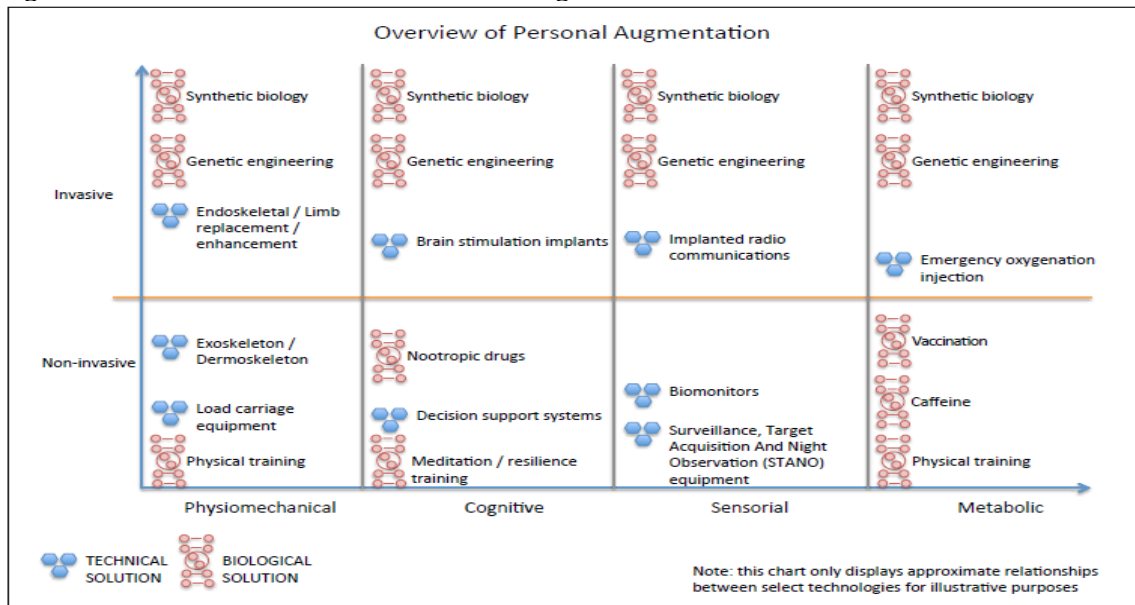
It is worth noting the US Congress has drawn a red line on creating human life from a genetically modified or enhanced embryo. The current legal restrictions prevent this concept from becoming a mainstream practice here in the US, but similar legal restrictions are not as prevalent in other countries.³⁷ According to the US Director of National Intelligence James Clapper, the advancements in human gene modification are a severe threat to national security. The US intelligence community has added gene editing to the list of “Weapons of Mass Destruction and Proliferation.”³⁸ These biological human enhancement solutions will only accelerate global interest in the topic and draw attention to the nation’s adversaries, which directly impacts the future operating environment. Fundamentally, the insatiable need for enhancing human physical characteristics and capabilities is the driving force behind these advancements, and the military is the primary audience.

The natural physical limitations of the human body could be a crutch in the application of warfare on the future battlefield. Combat operations against a near-peer adversary will be increasingly involved, and at the end of the day, speed will define success. In recent years, the gear and equipment have become more cumbersome and in many cases, unnecessary.³⁹ Nevertheless, physical requirements are becoming

increasingly intense and demanding for the vast majority of the US military, especially in the US Marine Corps.

The need for human enhancement and augmentation in the US Marine Corps is becoming increasingly important and worthy of additional research, study, and testing. In 2014, Major Max Michaud-Shield’s article in the *Canadian Military Journal* on personal augmentation provided an excellent illustrative example, outlined in figure 3, of technical and biological solutions for human enhancement in the military.⁴⁰

Figure 3: Fields of Human Enhancement and Augmentation



Source: Max Michaud-Shields Article Titled, “Personal Augmentation - The Ethics and Operational Considerations of Personal Augmentation in Military Operations.”

Additionally, Shields mentions, “The pace of development, due to commercial market pressures, will lead to enhancement technologies cropping up in civilian circles with a greater preponderance than in the military, as is currently the case with information technologies.”⁴¹ In the future, the private adoptions of many of these technologies, as we see now with Nucleus 7, will directly influence the moral and ethical considerations that these technologies currently present in modern day society.⁴²

Ultimately, the US Marine Corps should continue to invest in the research, development, and application of HET and augmentation for its service members. The lengthy study, debate, and discussion should occur sooner rather than later. Moral and ethical considerations aside, as Shields states, “The genie of military human enhancement will inevitably be let out of the bottle. We will have to ask how far we are willing to go in order to ensure the success and safety of our troops.”⁴³ The rapid technological and biological advancements in human enhancement and augmentation are now, more than ever, poised to influence the future operating environment. The ability for the US Marine Corps to generate and sustain significant operational tempo on the future battlefield is essential for continued success.

Additive Manufacturing

“You will not find it difficult to prove that battles, campaigns, and even wars have been won or lost primarily because of logistics.” - General Dwight D. Eisenhower

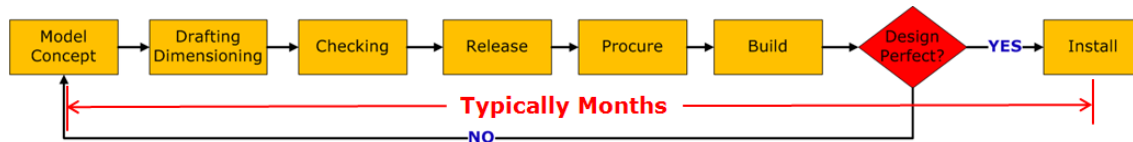
The final rapidly evolving technology trend is additive manufacturing (AM), occasionally referred to as 3D printing, and this technology will continue to impact the future operating environment well into the next twenty years. AM is the systematic layering of materials to create an object. Materials to create objects include metals, polymers, glass, chocolates, concrete, and more recently, human tissue and bone.⁴⁴ AM encompasses many technologies including subsets like direct digital manufacturing, layered manufacturing, additive fabrication, and rapid prototyping.⁴⁵ Current technologies to create printed objects require a computer, computer-aided design (CAD) or computer-aided engineering software, machine/printing equipment, and layering material.

The current manufacturing process to create an object using AM is relatively simple. According to the company, *AMazing AM*, “Once a CAD sketch is produced, the

AM equipment reads in data from the CAD file and lays down or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.”⁴⁶ Technological advancements within this process and the enhancements in each stage aim to maximize efficiencies while reducing waste and costs associated with production. The AM industry and market for this technology are growing substantially and are expected to increase and expand. The growth of the AM industry in the last thirty years is extraordinary, and the future application of this technology is bound only by imagination.

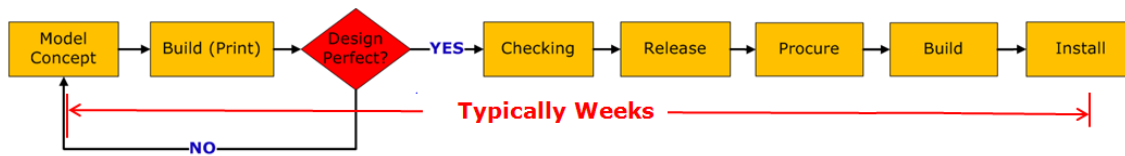
It all began in the early 1980s, when Dr. Hideo Kodama developed the 3D printing technique known as rapid prototyping, spawning the age of AM.⁴⁷ Rapid prototyping in AM is the layering-upon-layering of material to build an object. Since the 1980s, the entire AM industry has exploded. AM is already starting to impact every major commercial and defense industry. In 2014, forty-nine companies manufactured and sold industrial-grade AM systems, and in 2016, that number rose to sixty-two.⁴⁸ By 2025, the market growth across all industries for AM is expected to surpass USD 21 billion, with aerospace, medical, and automotive industries accounting for 51%.⁴⁹ In the next twenty years, manufacturing will become even more automated and data-intensive, replacing current traditional manufacturing techniques.⁵⁰ United Launch Alliance, a spacecraft launch company that serves the US government utilizes figure 4 and 5 to graphically depict the difference between the traditional manufacturing process and the rapid prototyping process using AM. By utilizing AM, design errors can be identified much earlier in the manufacturing process and can cut months off the entire development cycle.⁵¹

Figure 4: Traditional Manufacturing Process Flow



Source: Report on Additive Manufacturing Efforts and Applications in Expendable Launch Vehicles by Kyle A. Whitlow on May 1, 2015.

Figure 5: Engineering Process Flow Using Rapid Prototyping



Source: Report on Additive Manufacturing Efforts and Applications in Expendable Launch Vehicles by Kyle A. Whitlow on May 1, 2015.

Similar to United Launch Alliance, the benefits of AM can increase and enhance the US military's warfighting capabilities by redesigning the entire manufacturing process.

AM technologies can directly target the current logistical and sustainment capabilities of the supply chain system within the DoD. The utilization of AM technologies in the US military opens up a vast array of new opportunities. As Brett Connor stated in "Paradigm Shift: Additive Manufacturing and the New Way of War," "The payoff is that AM offers an opportunity for the DoD to move from the speed of conventional manufacturing to the speed of war."⁵² AM can provide the US military flexibility and speed for conducting and sustaining operations, especially in distant and austere environments of the future.

In recent years, the US military has recognized the benefits and the copyright and intellectual property challenges that AM presents, and has gone so far as to establish the DoD Additive Manufacturing for Maintenance Working Group (AMMO WG). The AMMO WG is "chartered to develop an integrated DoD strategic vision and facilitate

collaborative tactical implementation of AM technology in support of DoD's global weapon system maintenance enterprise."⁵³ The establishment of AMMO WG is an excellent example of combining private industry advancements in AM with military applications under the Cooperative Research and Development Agreement. The US Marine Corps's ability to leverage this revolutionary technology and deploy it to the tactical edge of the battlespace in the future operating environment, where inches could define success, may be the difference between mission accomplishment and mission failure.

In the very near future, AM has the potential to directly provide the US Marine Corps the ability to rapidly and efficiently create high-value products where they are needed most.⁵⁴ The high-value products that can be created utilizing future AM technologies include new microchips for highly advanced integrated command and control systems, critical avionics parts for Generation 5/6 fighters, specialized tools for repairing autonomous vehicles, and new lenses for directed energy weapon systems. Most importantly, AM can provide the US Marine Corps flexibility, while increasing operational readiness, and extending the logistics arm of the service.

Ultimately, the US Marine Corps should embrace and utilize AM technologies to the fullest extent possible. AM technology is still relatively new, and its benefits and potential applications are just now being discovered and explored. Technological advancements in AM are happening on a daily basis, across multiple industries, and the US Marine Corps should capitalize on these advancements as soon as possible and push it to tactical edge of the battlefield.⁵⁵ By pushing AM to the lowest reasonable tactical level, the technology can facilitate the generation and sustainment of an increased operational

tempo, especially when conducting operations in austere, remote, and decentralized command and control operating environments.

Conclusion

“Innovation is the only way to win.” – Steve Jobs

In general, the technological advancements in the last two decades have been incredible. The creation and widespread use of the internet has opened up entirely new frontiers. There are considerable benefits that these technologies provide, but they are not without risks; however, through active and robust cyber defense measures, the benefits of these technologies will far outweigh the risks. Most importantly, innovation has to be embraced and must continue to occur at all levels, along with a renewed focus on cyber and technological security. Secretary Mattis stated in the *Summary of the 2018 National Defense Strategy for the United States of America* that, “In the [increasingly complex security] environment, there can be no complacency—we must make difficult choices and prioritize what is most important to field a lethal, resilient, and rapidly adapting Joint Force. America’s military has no preordained right to victory on the battlefield.”⁵⁶ The future operating environment is inherently uncertain, but one thing is for sure, technology will continually challenge the fundamental character of warfare.

Technology will continue to grow at an exponential rate and expand across all industries and markets in the next twenty years.⁵⁷ The IoT will continue to proliferate and creep into every facet of daily life. AI will continue to define what “intelligence” really means, potentially possessing unfathomable capabilities through multiple applications. Human enhancement and augmentation will continue to be explored and implemented globally, while moral and ethical concerns fall by the wayside. AM advancements will continue to challenge the traditional manufacturing process and the current supply chain

system. The US Marine Corps needs to continue to open its aperture and take the necessary steps to explore these technologies and prepare for both their positive and negative impacts on operations.

Innovation and modernization will win the next war.⁵⁸ The US Marine Corps cannot expect to win tomorrow's conflicts with today's equipment, weapons, and gear. The US Marine Corps must continue to remain adaptable, resilient, and lethal in the future operating environment and on the multi-domain battlefield. The four game-changing and revolutionary technologies discussed here have the potential to impact every operational domain. To fight future battles, US Marine Corps leaders need to prepare for the impact of the internet of things, artificial intelligence, human enhancement and augmentation, and additive manufacturing, and be ready to leverage and employ or defend against these capabilities. The future success of the US Marine Corps depends on it.

Notes

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