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contemporary issues

Preventing Technological Failure in Future War
Special Operations Training Center: Does 3-Level Maintenance Training Belong?

Contemporary Issues in this edition of the Journal presents two articles: "Preventing Technological Failure in Future War" and "Special Operations Training Center: Does 3-Level Maintenance Training Belong?" In the first article Colonel Day contends that the challenge of avoiding technological failure and decisionmaking traps in the future intensifies as the environment becomes more complex and the processes of change continue to accelerate. He makes the case that staying current on future trends requires constant vigilance. Leaders must proactively face the future and its challenges, and seek the knowledge to prepare for it. The implications of not doing so could prove disastrous. The hope for the future lies in having adequately prepared leaders who understand their own shortcomings and the traps they are prone to, organizations that are set up for cognitive and structural diversity, and the right investments of our current resources to ensure the possession of the necessary technologies and weapons to wage war successfully in the nano-battlefields of tomorrow.

In the second article Colonel Miglionico asks the question "should the Air Force Special Operations Command (AFSOC) incorporate 3-level aircraft maintenance on-the-job training (OJT) as part of the Air Force Special Operations Training Center (AFSOTC)? He contends the current method of providing on-the-job training (OJT) for 3-levels using out-of-hide resources is adequate at best and needs improvement. If resourced properly with ample equipment and manpower, without degrading the existing aircraft maintenance organizations' productivity, then AFSOTC is a viable option for ensuring 3-level OJT. He provides a roadmap to do just that.

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Preventing Technological Failure in Future War

Allan E. Day, Colonel, USAF

Introduction

What today is a wild notion, based on science fiction, may suddenly mature into a useful technology with undreamed of capabilities.

Because of the growing complexity of "weapon systems"… and difficulties in disseminating this information, the potential for a technological failure (and technological surprise) not only lurks in the shadow but also becomes larger with time.

–Azriel Lorber, *Misguided Weapons*, 2002

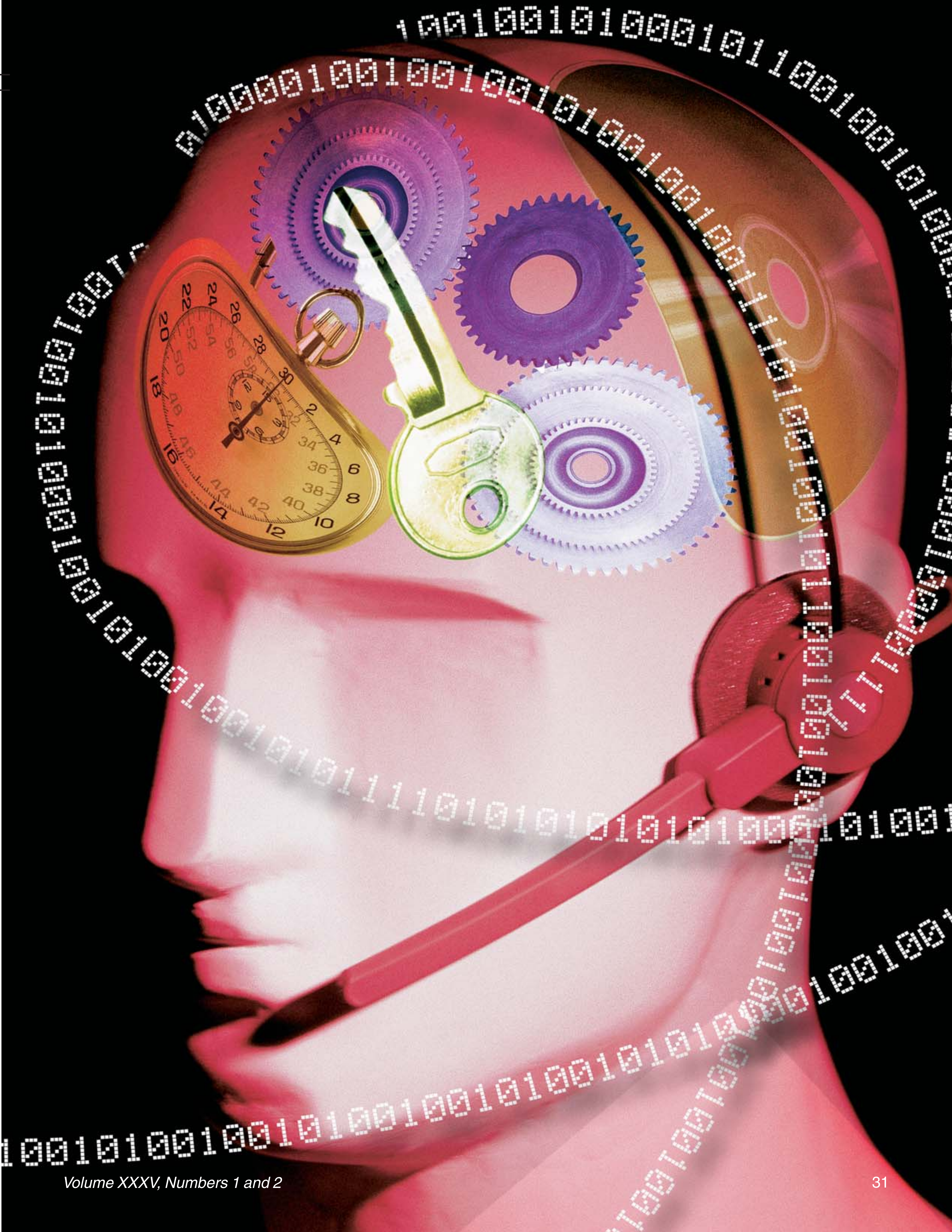
Making good decisions can be hard. There are many examples of senior leaders who failed to understand technology or disregarded its relevance to the battlefield. In some cases this was due to conservatism, pride, or even sheer stupidity, but in most cases it was due to an intelligent, well meaning leader inadvertently falling into a decisionmaking trap. While the concept of decisionmaking traps is not new, the future environment is introducing an entirely new set of challenges that are dramatically altering the way decisions are made on the battlefield. In this rapidly changing, technology charged environment, the effects of decisionmaking failure will be amplified and ramifications far more severe.

To prevent failure, leaders must first understand the environment by staying engaged through self-study. They must become familiar with terms associated with and the implications of concepts such as nanotechnology, quantum computing, biomimetics, artificial intelligence, and nanobots. Linear thinking must be replaced with intuitive leaps to account for the exponentially changing global environment. They must understand how the new flattened world gives rise to threats and opportunities across the spectrum from state actors to empowered individuals.

This article provides insights into the world of nanotechnology and its impacts on the future battlefield environment that will drive decisionmaking today. The first sections serve as a short tutorial on the future environment. In the first section, the basics of nanotechnology are discussed along with working definitions of terms used throughout the rest of the article. The second section looks at the interaction of nanotechnology with a number of other fields such as biomimetics, genetics, robotics, information, energy, and artificial intelligence.

Following the discussion on nanotechnology in different scientific fields, section three provides a discussion about the changing future environment. It provides a discussion of linear versus exponential thinking, the effects of globalization on nanotechnology research, and the growth of India, China, and Russia as competitors for dominance in the nanotechnology market by 2035.

Section four then pulls the concepts together to explore the converging trends and the implications on the 2035 battlefield. It then provides a short discussion of four



competing views about what the future will be like. This general discussion of the future environment will also provide insights into the second and third order effects of nanotechnology on the future 2035 battlefield based on nanotechnology advancements and their implications for national defense. With the basics of nanotechnology understood and the implications and effects of nanotechnology considered for the future battlefield, the next step is to consider how senior leadership must respond.

Section five looks at decisionmaking traps that could lead to technological failure by disregarding, misapplying, or misunderstanding technology. This is not failure of technology, but instead it is human leadership failure to inadequately respond to or understand the game-changing nature of advances in technology. The section describes nine different traps, giving examples from past history, and then goes on to provide concrete ways to steer around each of the decisionmaking potholes.

Section six gives recommendations for disaster-proofing senior leadership against making bad decisions, especially those leading to technological failure. It looks first at important aspects of preparing leaders for success in this new environment, then looks at developing better organizational strategies, and finally ends up exploring the best options for investing resources to keep the United States (US) in a position of technological leadership.

As the environment becomes more complex and the processes of change continue to accelerate, the challenge of avoiding technological failure and decisionmaking traps in the future intensifies. Technological trends coupled with globalization will drive the world's economies not on a linear slope, but on an exponential trajectory. Ubiquitous communication, massive data storage, unfathomable computer processing speed, intrinsic artificial intelligence, miniaturization to the atomic level, along with the pervasiveness of the Internet will continue to converge to drive technological improvements to a level many are afraid to consider today. Leaders must not shirk this challenge; they must face the future and seek knowledge to prepare for it. If leaders fail to make the right choices today, the ability to gain victory in future battles will be lost.

What is Nanotechnology?

Although this article is about leadership decisionmaking, leaders must understand at least the basics of nanotechnology and terms related to its use as it will have a major impact on nearly every aspect of the future battlespace. Thus, to make informed and wise decisions regarding the future, leaders must know about nanotechnology. Although it is not necessary to be experts on the cutting edge of science, leaders must understand enough about emerging technologies to visualize its potential uses and recognize its dangers. The following three sections will serve as a short tutorial on nanotechnology to assist a senior decisionmaker in understanding the underpinning technology fueling the future.

Article Acronyms

AI – Artificial Intelligence
MEMS – Microelectromechanical Systems
NEMS – Nano Level Equivalent Machines
Nm – Nanometer
US – United States

Nanotechnology is defined as "an ability to fabricate structures of individual atoms, molecules, or macromolecular blocks in the length scale of approximately 1-100 nanometers (nm)."[1] It is applied to physical, chemical, and biological systems. Nanotechnology differs from other technologies in three key and unique characteristics: size, fabrication techniques, and interdisciplinary nature.

First is size. Nanotechnology is the next order of magnitude smaller than microtechnology. In the 1980s and 1990s the cutting edge of technology was in microelectromechanical systems (MEMS). The scale of MEMS is from 1-100 microns (10^{-6}).[2] MEMS enabled numerous electronic, biological, and mechanical breakthroughs. The nano level equivalent machines, NEMS, are a thousand times smaller (10^{-9}) than MEMS.

The second unique characteristic of nanotechnology is its method of fabrication. While MEMS are manufactured using the same etching and building up techniques as the semiconductor industry, NEMS are so small they go beyond the ability of standard photolithography to gain the precision required for manufacturing.[3] This process is significantly more challenging. Two approaches are used—the top-down approach and the bottom-up approach. These will be explained in more detail later.

The final unique characteristic of nanotechnology is its interdisciplinary nature. The fact that all matter consists of atoms brings home the unique nature of nanotechnology. When building a structure atom by atom, the macro scale result can cross the traditional stovepiped scientific boundaries. Scientists can arrange atoms to form a new structure with properties that could be useful for new vehicles, energy gathering, or even the human body. In addition, traditional biological molecules like DNA can be used to construct molecular electronic circuits to build the next generation of quantum computers.[4] At the nanoscale, all fields of science are equal and there are no stovepipes.

Top-Down/Bottom-Up Approach

Computer chip manufacturing is a classic example of the top-down approach. The ability to get more power from the same silicon wafer comes from the ability to pack more and more transistors in a smaller and smaller area. In the span of a few decades technology has gone from vacuum tube to integrated circuits that provide the power *under the hoods* of modern computers. Getting to the nanometer scale in integrated circuits is becoming more and more challenging using typical top-down silicon manufacturing techniques.

This challenge is illustrated by Moore's Law. In 1965, Gordon Moore, the founder of Intel, predicted that the number of transistors on a single silicon wafer would double every 24 months and this became known as Moore's Law.[5] Moore foresaw that with increasing precision, smaller and smaller photolithography mask structures could be developed to enable smaller spacing between transistors on an integrated circuit.[6] As the spacing becomes closer, the computing capacity per unit space on the silicon wafer increases. The greater the computing capacity, the more complex computations it can make in an ever decreasing space.

Military leaders must keep an eye on the trends with respect to computing power as it is the great underlying enabler for the design and use of all major weapon systems. Differentiating between what is possible and what is probable is a key part of decisionmaking calculus each leader must understand.

In contrast to the top-down approach, the bottom-up approach to building computers involves manipulating atoms and engineering materials from the bottom up just as nature does. Thus, instead of trying to shrink lithography technology to ever smaller limits, it uses the properties of atoms and molecules themselves to generate switches and transistors. This nanotechnology is what most refer to as *molecular* or *quantum electronics* and is the "primary contender for the post-silicon computation paradigm."[7]

When dealing with particles on an atomic scale, the effects of Newtonian physics such as gravity, magnetism, and electricity "are no longer dominant, the interactions of individual atoms and molecules takes over."[8] According to Lynn Foster, author of *Nanotechnology: Science, Innovation, and Opportunity*, moving to a level of 100 nanometers and smaller, "the applicable laws of physics shift as Newtonian yields to quantum."[9] The power and hence the challenge, is taking advantage of the quantum effects and drawing them into the macro world.

Aluminum provides a simple example of how properties change at the atomic level. If a thin sheet of aluminum is cut into small pieces, the properties of those pieces are similar to that of the bulk aluminum until the nanometer level is reached—when the pieces of aluminum will spontaneously explode.[10] This fundamental change in properties of a material at the atomic level is being studied by scientists in the fields of chemistry, physics, materials, medical, and so forth to develop novel approaches to solving previously impossible tasks.

While the top-down approach will eventually have to reach a physical limit, the bottom-up approach has no such limitations. Building structures atom by atom opens up the doors to fantastic possibilities in any field given the right tools to manipulate the atoms.[11] One of the most exciting emerging technologies is molecular self-assembly. This involves building molecules using engineered viral strains and basic human self-assembly elements to grow certain molecular structures.[12] In the arena of electronics, building circuits using this approach is likely the next paradigm beyond integrated circuits.[13]

Foster articulates five reasons molecular electronics will be the next paradigm for the continuance of Moore's Law. The first reason is size. In 2002, IBM built a "three-input sorter" to "arrange carbon monoxide molecules precisely on a copper surface." This circuit is "260,000 times as small as the equivalent circuit built in the most modern chip plant."[14]

The second reason is power. Transistors are inefficient and generate excessive heat when performing operations. This is in contrast to human brains that are "100 million times as efficient in power and calculation as our best processors."[15] While human brains only operate at 1 kHz, they are "massively interconnected and folded into a 3-D volume."[16] This means that the measure of merit is not necessarily going to remain clock speed, the number of calculations per second, but may move to the number of calculations per unit volume. The third reason is manufacturing cost. Manufacturing molecular electronics can be built through "spin coating or molecular self-assembly of organic compounds."[17] Instead of being engineered from the top which requires ultimate precision, molecular self-assembly will not necessarily be ordered and precise as top down precision is understood today. The atomic forces themselves will dictate the shape and form of the circuitry as it builds from the bottom up. The ability to start a process and allow the circuitry to *build itself* could significantly decrease manufacturing costs.

The fourth reason is low-temperature manufacturing. Since much of molecular manufacturing may involve the use of biological molecules, the manufacturing process will proceed at room or body temperature versus "1000 degrees in a high vacuum"[18] required for silicon processing. This opens up the possibility to use cheaper plastic substrates to grow these molecular electronics.

Finally, Foster writes that the molecular electronic solutions are inherently digital and nonvolatile. This is far superior to the top-down, inherently analog, and leaky solutions that try to approximate digital methods and nonvolatility.[19]

One can see that nanotechnology will form the basis of most of the technological advances in the future. The ability to form materials and structures atom by atom will have wide ranging applications that have serious military and national security implications. Maintaining awareness of this exploding research area must be a part of every leader's crosscheck.

Converging Research with Nanotechnology

Because of its atomic-level character, every field of science has been impacted by nanotechnology. One of the most unique aspects of this power of the small has been the convergence of scientific fields. Scientists have rediscovered the homogeneous nature of science at the molecular and atomic level. This means discoveries at the atomic level in biology, engineering, or chemistry can be directly translated over to other fields like medicine. Medical needs, such as helping wounded soldiers, can drive teams of researchers together from a number of disparate fields to arrive at solutions to complex problems.

This section looks at a series of key areas where nanotechnology could have its greatest impact on the future battlefield environment. These key areas include biomimetics, genetics, robotics, information, energy, and artificial intelligence. Senior leaders must stay *tuned in* to developments in these nano-fields to make informed and accurate decisions about investments and what these technologies mean for the US and her enemies.

One particularly telling example of the crossover between different fields of science is biomimetics. The science of mimicking systems found in nature with things made in the laboratory is known as biomimetics. It has produced a whole host of technological breakthroughs through the years. For instance, the repellency and self-cleansing aspects of lotus flowers inspired new coating technologies now called the *lotus effect*. Scientists used the concept of echolocation discovered in bats to develop sonar and radar as well as sonograms to view inside humans.[20] In ancient times the study of birds inspired flights of fancy such as that of Daedalus in Greek mythology and early aero engineers such as da Vinci whose *Codex on the Flight of Birds*,[21] provided his translation of bird flight into machine technology.

Today, miniaturized aeronautics and computer technology have spawned the ability to build flying machines that even da Vinci never dreamed of. The merging of energy, propulsion, computation, and aeronautics on the micro level has resulted in aero vehicles the size of dragon flies with mosquito-sized vehicles on the way.[22] The ability to produce miniaturized flying vehicles opens the door to miniature payloads as well. In his review of many of these amazingly small air vehicles, William Davis has explored the potential military uses of nano air vehicles which measure less than 7.5 centimeters and weigh less than 10 grams.[23]

The future missions of nano vehicles are only limited by one's imagination. Clearly intelligence gathering, surveillance, and reconnaissance will be key mission areas. But many others can be imagined. For instance, with a structure made of explosive material, the nano air vehicle could be the ultimate in precision weapon when coupled with object and face recognition technology (available today) and autonomous control. A nano air vehicle could be released and sent to find its target in a nonpermissive, Global Positioning System (GPS) jammed environment. These nano air vehicles could also be equipped with biological and chemical sensors for use in a battle damage assessment or for post-weapons of mass destruction (WMD) clean up operations. In a failed state scenario, a swarm of nano air vehicles could provide insight into the spread of disease and even administer inoculation.[24]

Biomimetics is also spawning research into better understanding the human being—everything from decoding the human genetic fingerprint, to replacing war damaged or defective body parts through robotics, to mapping the brain functions. The miniaturization of transistors and computing technologies has been used to mimic the synaptic firing of brain components.[25] By mapping the brain's functions, replicating its most basic components, and using massive computing speeds similar to those of the brain, it may be possible to produce a working brain made of silicon chips. Several research centers, such as IBM's Blue Brain project, Howard Hughes Medical Institutes's Janelia Farm, and Harvard's Center for Brain Science, are working on this challenge.[26] The further along this path of brain replication the researchers go, the more possible it becomes to degrade or improve the function of the brain which will have significant battlefield implications. And this example represents just one small area when compared to the vast promise that comes from nano science. While biomimetics seeks to understand how to replicate any part of nature including humans, human genetics research hones in on the fundamental molecular processes that produce the human body and allow it to function.

In 2003, the Human Genome Project completed its 13-year effort to understand and sequence humanity's most basic genetic building blocks.[27] While a detailed discussion of genetics is beyond the scope of this study, a basic understanding of the key elements and the impacts of the completed genome project is warranted, as the force of this massive undertaking will be felt for years and will impact military operations.[28]

From a biomimicry standpoint, understanding the basic functions of human life can help replicate and manipulate the human body's most important components using artificial means. Scientists have been able to grow engineered human tissue using adult stem cells to form body parts that can be transplanted into a human body without the use of antirejection drugs. Military researchers have recently found a way to regrow the tip of a finger with plans to regrow damaged limbs.[29]

The more researchers work to solve the puzzles, the more synergy and the faster the solutions come. One of the goals of the genome project was to provide the information gained to the private sector. This puts the power to do research, create new tissue, discover cures, and understand how life can be extended into the hands of the world. As in most things, the power to do great good is coupled with the power to do great harm. Where some see an opportunity to improve humanity, others see an opportunity to hold humanity hostage or gain an advantage by creating new incurable diseases or other destructive effects using this same technology. Therefore senior leaders must stay cognizant of the advances in genetics since much data and capability will flow from the medical side to the military side with ramifications from the tactical to the strategic level of operations. With increased understanding of how humans are put together, scientists have sought to build robotic imitations that replicate various functions of the human.

Robotics is already impacting the battlefield and will only become more important in the future as robots get smaller and more capable. This fact means senior leaders must understand the fundamentals of robotics and keep up with the breakthroughs as they happen. Macro level robots are already a standard part of the requirements to do DoD's mission. They are used for aerial reconnaissance, forward sensing around corners, on ordnance disposal teams, and even for performing remote surgeries.[30] Remote surgery can bring lifesaving capability to anywhere in the world. The ability to have the world's best available doctor perform a vital surgery via satellite link using a medical robot is not the stuff of science fiction, it is here today—in fact it has been in use for nearly a decade.

The real excitement (or potential concern) in robotics begins to take shape at the micro scale and below. On this scale scientists are already working on swarm technology to control vast hordes of miniature flying and ground based sensors. Below the micro scale to the truly nanoscale robotics, the possibility of another nanotechnology Holy Grail, self-assembly, comes closer to reality. Professor Carlo Montemagno, of the University of California, Los Angeles has brought together biotechnology and nanotechnology in a very unique way. He used rat heart cells to *grow* muscular tissue over a silicon nanostructure to produce miniscule robots less than a millimeter long that "can move themselves without any external source of power."[31] According to Montemagno, these robots are living organisms that grow and multiply because they are alive.[32] On an even smaller scale researchers are developing nanoscale robots, or nanobots, that can move in a specific direction along a path. For example, scientists from the University of Oxford "have created a two-legged, nanoscale robot that can walk unaided along a single strand of DNA more efficiently than all previously created nanobots."[33] The ability to create a robot of this size now opens the door for other research to combat disease or mitigate chemical or biological effects at the cellular level.

In the medical world, nanotechnology is being used to find and target particular bad actor cells. Scientists are using nanoscale crystals that emit different colors of light when irradiated with energy, to find cancer cells even in very small concentrations. Once found, these cancer cells can be specifically targeted. While still a few years into the future, nanobots are being developed to be injected into the human body to target and apply a dose of chemotherapy cure directly to these malignant cells. This type of precision strike could dramatically improve cancer treatment success rates and reduce the devastating effect of cancer treatment on the human body.

From a national security standpoint, nanobots that can find and target malignant cells would also be capable of targeting other cells. The possibility of self-replication combined with programmable nanobots that target certain types of human cells creates a very challenging scenario to consider for future adversary tactics. While much of the research on self-replication and nanorobotics is still in its infancy and primarily in national level laboratories, the next topic, information technology, is not. It has already moved down to the nonstate actor and individual level.

Information flow has changed in both form and forum over the past two decades and will continue to change in the future. Staying connected has gone from writing letters (now known as snail mail), to sending e-mail, to texting. Social interaction that used to be handled face-to-face or over the phone, has now moved to writing on cyberwalls[34] at social Web sites like YouTube, Facebook, Twitter, and others.

While much that takes place using these cyber-walls is harmless fun interaction, these same cyberwalls have become key to understanding how networks grow and respond to inputs.[35] Most of the news networks now have a Web presence because print news and even broadcast news cannot keep up with the flood of information available on the World Wide Web.

As terrorists and other adversaries move operations to the Web, they can become stealth entities, coordinating actions, striking, and withdrawing without leaving many clues to follow. Because of the availability and the low cost of these information tools, they are available to anyone with an Internet connection and a minimal knowledge of how to operate in the info sphere. Terrorists have used cyberwalls to organize themselves and uplink gruesome footage of brutal killings, beheadings, and other despicable activities to bring attention to their cause.

As more personal, medical, and professional information becomes digitized and available online, vulnerability to cyber attacks from state and nonstate actors increase. A recent example of the devastating nature of a coordinated cyber attack was when Russia brought down key Georgian Web sites just prior to invading in the fall of 2008.[36] In November 2008, cyber attacks on the Pentagon resulted in a DoD-wide ban on external multimedia and USB drives in DoD systems because there was evidence that an infected USB drive inserted into a DoD system caused a vulnerability. These two recent high-visibility attacks highlight just how vulnerable digital media can be to a knowledgeable adversary. Thwarting these attacks is a full-time job for cyber warriors because new and innovative threats are being developed every day. There is no doubt information protection will have to be a major portion of every major decision carried out today and in the future. Without secure information flows, decisionmakers will become severely handicapped.

Nanotechnology may provide both a problem and a solution to information protection. Information protection today relies on data encryption. Today encryption keys are 128 or 256 bits long, forcing a computer to solve for every permutation and combination of potential options to arrive at the key. Quantum computing will break this paradigm as it could break today's best encryption keys in a fraction of a second. This will be a total disaster for the information security of the entire world once the first quantum computers arrive on the market.

Nanotechnology research has also provided a potential solution called quantum entanglement. In quantum entanglement, pairs of photons, or qbits, are linked to each other such that a change in state of one photon of the pair results in the same exact change in the state of the other photon of the pair regardless of the distance between them. How this phenomenon works is still unclear, but researchers are developing *uncrackable* quantum encryption codes using quantum entanglement.[37]

With quantum entanglement, data may be secure from hackers, but the cyber war will continue as new viruses, Trojan Horses, and other malware continue to probe US cyber defenses for even the smallest defects. The ability to maintain a leading edge in nanotechnology research and to respond quickly and effectively in this emerging infosphere, will determine failure or success in future wars that use this technology. The willingness of one leader to accept risk in the information sphere can have a dramatic effect on the entire network. Because the US and other nations rely so heavily on the information networks and require them to sustain daily operations in peace and war, this is an area every senior leader must understand. As information networks enable more of the world to engage in the market, the quest for energy will become greater as well.

Energy generation and storage will play a major role in future conflicts. As globalization brings more people out of poverty and into market economies, the energy requirements to fuel the massive worldwide industrial complex will double the current requirements by 2030.[38] The rapid growth of China, India, Russia, and other smaller nations will drive an ever increasing need for these limited resources and lead to conflict. Nanotechnology is playing an increasing role in solving the future needs for energy generation and storage, but without significant investment, energy will still be the major source of conflict in 2035. Senior leaders must stay tuned to changes in the energy landscape to ensure the US can meet its energy demands in the future regardless of where conflicts arise. After energy, the final area that will directly impact the battlefield and hence, the decisionmakers of the future is artificial intelligence.

In many ways, the quest for artificial intelligence (AI) brings together all the concepts discussed thus far—biomimicry, genetics, robotics, information, and energy—to inform research into making intelligent machinery. The ultimate goal of most AI researchers is to achieve a machine that can match or exceed the thinking capabilities of a human. Once this happens, human decisionmaking will be challenged by machine decisionmaking.

As nanotechnology enhancements bring more computing power and these ever more powerful computers become more pervasive, they also become much more indispensable. Today's society already relies on *intelligent* machines to take in volumes of data from multiple sources, collate it into logical informative categories, and provide the optimal course of action. Massive supercomputers model the effects of nuclear detonations and the spread of weapons of mass destruction, as well as provide the optimal courses of action based on all source intelligence.

As machines become more capable of making projections and are seen as providing better outcomes than even the smartest humans, their results will be used as the benchmark to measure human performance. Today, many human-centric processes have now been obviated by machines. As the number of human operators and analysts gets reduced, senior leaders will be compelled to rely almost solely on synthetic analysis from a computer.

As more biological processes are modeled and programmed into software, the ability to mimic nature will continue to advance. Already machines have been programmed to simulate numerous scenarios to test human skills. Advanced AI research has enabled the move to virtual training. The ability to produce synthetic realism in flight simulators, law enforcement training, and surgical procedures training has both reduced the costs of training, but it also has increased its effectiveness. Virtual training is now becoming ubiquitous and has taken over for *hands-on* training in many areas. The Air Force has even used computer simulation to provide interactive cultural awareness training to all of its personnel.

As the artificial environment becomes more realistic through advancements in AI converged with nano-enhanced tactile sensors, robotics, and information technology, the ability to provide realistic scenarios between dispersed personnel can only increase. While this will surely enable training opportunities, it will also enable dispersed adversaries similar capabilities to converge their disparate numbers on a single domain for training and in some cases, execution.

As scientists get closer to creating a machine that thinks equal to or better than a human, the battlefield environment will become much more challenging for anyone not having this type of capability. The ability to leverage the advances in AI and virtual reality training will be the mark of a successful future leader. To leverage this type of technology, one must actively follow its development. Senior leaders must maintain a close watch on progress in AI as it is advancing in both the private and public sectors and could easily emerge in the hands of an adversary and bring a significant advantage at low cost.

Exponential Thinking and Globalization

In the future, leaders must think differently if they are to be effective decisionmakers. The combination of exponential acceleration and globalization will drive a dramatically different future that many senior leaders are unwilling or afraid to consider today. The smug attitude behind the phrase, "I am an analog guy living in a digital world" will not suffice in this future environment. According to Stephen Shambach, Director of Leader Development at the United States Army War College, "strategic leaders must possess a broad understanding of relevant military technologies and understand how advancements in each of these technologies can be incorporated … to permit continued advancements in combat effectiveness and efficiency."[39] He goes on to state that technology is like a two-edged sword—with increased capabilities come new and different vulnerabilities. Thus, the fact that technological breakthroughs can enable more effective combat power for the nation is coupled with the fact that this same increase in technology can drive asymmetric advantages to America's enemies. Here is where the understanding of the future convergence of the exponential growth of nanotechnology and globalization becomes critical for senior leadership.

Law of Accelerating Returns: Linear versus Exponential Thinking

Most humans think linearly. Senior leaders are notorious for making pragmatic, ploddingly linear decisions especially when faced with breakthrough technologies. Bureaucracies exacerbate the problem as they are driven to maintain status quo and prevent disruptive course corrections even in the face of direct evidence for dramatic change. Why? From observations in the past, it is easier to project the future using a linear extrapolation from today and use that same line of thinking in the future. When two points on a straight line are known, one can solve for the future. As a method of making future prognostications, straight line projections tend to be forgiving, kind, and comfortable. That is why they are used so frequently. Unfortunately, they are also very dangerous when the future end state is not anywhere near the linear end state.

Leaders must learn to think exponentially. Exponential growth curves are not as kind or calming and are much less forgiving when considering future projections. Whereas slight changes in assumptions and small miscalculations can have small effects on the end state in linear projections, these same slight missteps will produce radically different end states on an exponential curve. Figure 1 shows a comparison of different growth curves.

Note the difference between the linear growth line and the two exponential growth lines. The exponential lines begin with a low slope that in the short term looks linear, but at some point, the technological

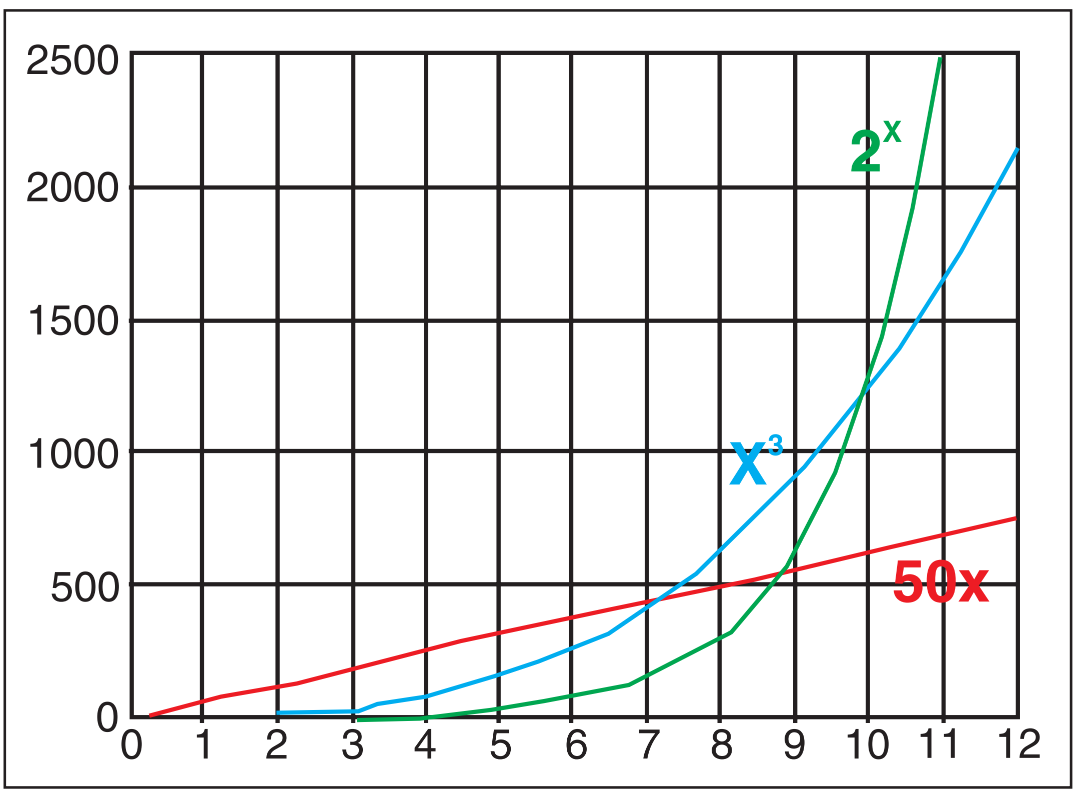


Figure 1. Exponential versus Linear Curve Comparison[40]

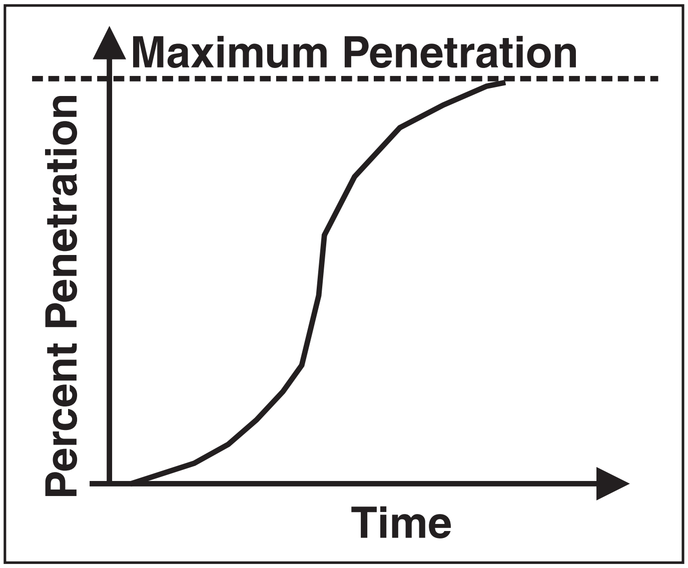


Figure 2. Generic S-curve

maturity reaches the point where it takes off on the exponential rise. Assumptions made during the *linear* portion of the growth curve will not just be a little wrong; they can be catastrophically deceiving when considering the eventual end state. Another aspect of an exponential growth curve is that small actions taken or investments made in the beginning of the growth curve can have dramatic effects on the eventual outcome.

When it comes to understanding the exponential growth of technology, one must also understand the concept of S-curves. The generic S-Curve shown in Figure 2 depicts simple market penetration of a new technology.

The lower end of the S-curve shows the time a new technology spends in invention, development, and market evaluation. As a new technology is adopted over time, it moves along the S-curve and gains market penetration slowly. At some point, the technology hits a Gladwellian *tipping point*[41] and takes off. The market penetration rises rapidly until market saturation or arrival of a competing technology. The curve flattens, illustrating a time of diminishing returns.

Figure 3 provides a labeled depiction of this same curve describing time versus commitment.[42]

It can be seen that as time moves to the right, commitment to a new idea or technology grows slowly at first as the awareness spreads. Once the concept becomes understood, it can take off and be adopted by more people until it becomes an institutional concept. For example, the Microsoft Suite of programs began slowly 26 years ago and has followed this cycle to the point that it is now institutionalized across the entire world. To maintain its growth, Microsoft needs to continue building new innovative products that will extend its curve. S-curves are useful for showing other trends such as applied effort versus advancement as shown in Figure 4.[43]

This type of curve shows significant effort is required to advance a technology in the early stages of its life, then, just after the tipping point, a technology will advance rapidly without a significant investment in effort. After market saturation, the curve bends over and begins to flatten. Significant effort is then needed to push that particular technology further. Also shown in Figure 4 is an illustration of what happens when a new breakthrough in technology in a related field causes an advancement of momentum. This new advancement continues the previous S-curve as it starts at the tail and continues to advance from there.

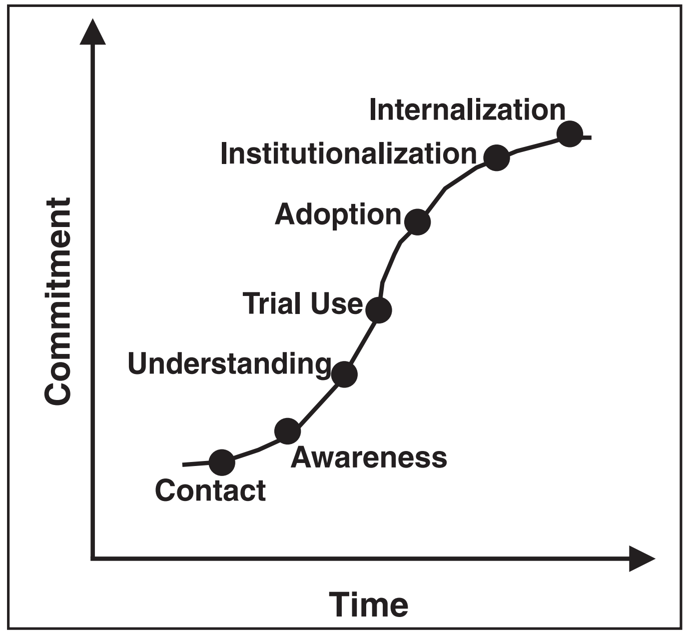


Figure 3. Labeled S-curve Stages of Commitment Over Time

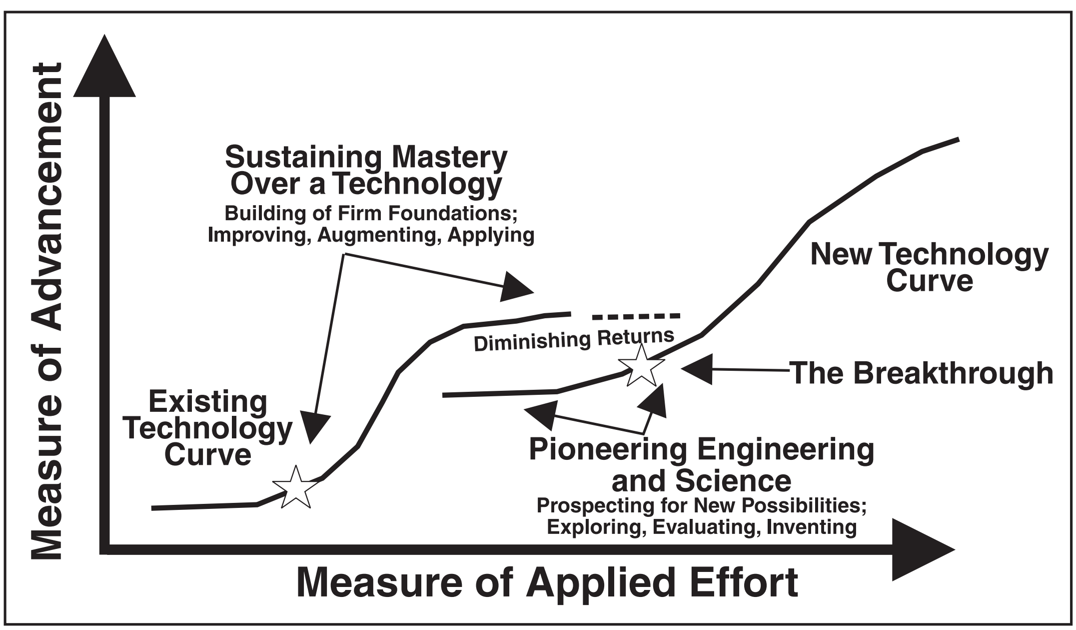


Figure 4. Cascading S-curves

The result of this type of S-curve cascade is an exponential curve as each successive S-curve is propelled faster and reaches higher than the previous S-curve. The end result is an acceleration of advancement for key technologies. As the S-curves cascade, it takes less effort to gain more advancement to a point when the resulting exponential curve can theoretically reach a point of vertical growth when a technology could advance without applied effort or human intervention.

Based on the accelerating S-curves model, the future cannot be predicted using simple linear extrapolation. Exponential thinking forces leaders to think of the future as a complex interaction of multivariable equations that will drive out certainty and insert risk in their projections. Risk is inherent in every problem, but the ability to define risks and reduce them will be directly proportional to one's ability to think exponentially. Not only must senior leaders think exponentially, they must think globally.

Globalization Effects: Low-Cost Manufacturing and Cheap Technology

Globalization is defined as "the process by which the people of the world are unified into a single society and function together."[44] Thomas Friedman describes it as a "flattening" of the world. While there are other descriptions that may apply, in its most basic form, globalization entails the interconnectedness between people around the world.

The process of globalization has been enabled and enhanced by many factors, but Friedman points out one of the biggest factors was the massive $1T effort to "wire the world" with fiber optic cables.[45] Fiber optic communication coupled with ubiquitous, low cost computers, telephones, and market-driven competition served to draw more and more of the world's population onto the Internet. Once there, business interactions became possible and companies reached offshore to outsource their service sectors to cheaper labor markets. For example, the ability to tap into thousands of graduate students and computing experts at bargain prices across the oceans in India and Malaysia caused companies like Dell and HP to outsource their call centers. Many other companies have followed suit.

Globalization will continue to have a dramatic effect on the future environment—economically, technologically, socioculturally, and politically.[46] The recent economic meltdown experienced in America had an equally deleterious effect on the rest of the world's financial markets due to this massive interconnectedness. Similarly, the entire world watched the 2008 American presidential election with rapt attention as they knew it would have a direct effect on them as well.

The impact of globalization on the future operating environment of 2035 can be looked at through a number of different lenses. The following analysis will focus on the *nature* of globalization and how it will change the world stage in the future and thereby impact the decisionmaker's global frame of reference.

Globalization's power and impact has had its most visible effects in the economic realm through the lowering of trade barriers and enmeshing of markets. In his book, *The World is Flat,* Thomas Friedman provides insight into what he sees as a progressive flattening and shrinking of the world. He suggests the world has moved from Globalization 1.0 which, from an American perspective, began in 1492 when Columbus sailed to the Americas to open trade routes. This phase of global integration dealt with states expanding their trade agreements between other states. From 1800 to 2000, Friedman suggests a new era, Globalization 2.0, began with the industrial revolution and the advent of multinational corporations. As transportation and telecommunication capability increased during this phase, the cost of transporting goods and communicating between countries decreased dramatically, accelerating the rise of a vast global economy. At the end of this era, we see the beginning of e-businesses as the Internet becomes ubiquitous. Beginning in 2000, Friedman describes a distinctive change in the nature of globalization to what he calls Globalization 3.0 or the rise of the empowered individual. This new environment is built around a flattened world and underpinned by "the combination of the PC, the microprocessor, the Internet, and fiber optics."[47]

Looking at the move from Globalization 1.0 to Globalization 3.0, there are a number of obvious trends. First, each phase has become more specific—from state-to-state interaction, to multinational corporations, to empowered individuals. Individuals can now interact using text, video, and avatars (virtual digital representations) with other entities (human and machine) all over the world via high speed fiber optic networks.[48] Second, the rate of change has also increased. Globalization 1.0 lasted just over 300 years. Globalization 2.0 was 200 years. If the trend continues, there could be a more specific globalization phenomenon beyond Globalization 3.0, where the empowered individual becomes the empowered machine-enhanced human or cyborg in 50 to 100 years. This merging of machine and man fits with observations from the above discussions of biomimicry, robotics, and genetics. Ray Kurzweil predicted this combination of man and machine nearly 20 years ago and called it the "singularity."[49]

The move from Globalization 1.0 to 3.0 also shows the rise of three nations that many predict will rival or surpass the United States' share of the global marketplace—India, China, and Russia. This has serious national security implications. How should America look at these emerging superpowers? Basically there are three options—threats, customers, or opportunities.[50] The negative view would see these rising powers as threatening competitors with aggressive intentions that could destabilize the world balance of power. This view would put them on an axis of evil list and potentially drive them further down an adverse path. A second, more encouraging view would see these three populous nations as an opening to a larger trade market with a huge and growing potential customer base. The third view would see the growing power and influence of these three nations in their regions as an opportunity. The interconnectedness of all nations could facilitate burden sharing. Taking this more positive approach to research, development, manufacturing, and security with each rising state actor able to *pull its own weight* to benefit the whole, could result in a more peaceful multipolar world.

United States' leaders must be cautious of treating all rising powers as threats. In just over a decade the formerly opaque nations like China and Russia have become more translucent as they open up their borders to new trade opportunities brought forth by globalization. If former arch enemies can become members of the World Trade Organization and active partners in the global marketplace, then any country can. While the US must keep an open mind to opportunities, it must also keep both eyes open. The US cannot look past clear threats from these or other rising powers nor can it assume a rising power is automatically a threat. US leaders must have a balanced approach to foreign policy in this flattened world, but they must also understand how the nonstate actors like international corporations and individuals are being empowered by this new environment.

Ubiquitous communication and globalization has redefined how international corporations and businesses form and organize. Businesses no longer need to have large office buildings to operate. Individuals can organize into flexible organizations that form themselves based on the problems they come together to solve. Expertise can be harnessed from anywhere in the world to tackle tough problems. Companies now can keep a very small cadre of core business managers and outsource key expertise as required. In this type of fast paced environment where deals are made, problems are solved, and money changes hands all in the digital realm, the ability to maintain dominance using conventional thought processes and linear thinking would put a country woefully behind the power curve. Individual leaders must be enabled and empowered to operate in this new, more horizontal environment. While globalization brings with it many opportunities, it also brings many challenges. The leaders that stay engaged and informed about the rapidly changing global environment will be effective and relevant; those that do not, will no longer have the capability to lead effectively.

Future Key Players in the Nano Marketplace: India, China, Russia

India, China, and Russia have come to realize the value of nanotechnology and are using their education prowess, in varying degrees, to wrest control of the nanotechnology market from the United States. Senior leaders must understand the nature of the rise of these key players to make accurate decisions about the future global environment.

India is increasing her nanotechnology research budgets and seeks to increase her economic well-being, but also wants to use nanotechnology to serve her people. India invested $250M in starting a national nanotechnology initiative to coordinate national efforts. From the private sector, the cofounder of Hotmail, Sabeer Bhatia, has invested heavily to "build a multibillion dollar nanocity" in northern India.[51] Rachel Parker, a University of California Young Scholar points out that the focus of the nanotechnology research in India is not on weapons technology, but is primarily on social assistance for India's preindustrial age population. Nanotechnology research will focus on improving agriculture, health, and poverty as well as reducing air, water, and soil pollution.[52]

According to Alexis Madrigal's reporting on Chinese nanotechnology, China aims to "leapfrog the United States in technological development" by 2020.[53] Forbes.com writer, Josh Wolfe, suggests that China is putting her money behind her desires. In 2005, China was number two behind the United States in nanotechnology research investment reaching the "equivalent of $1.11B, compared with $1.57B in the United States."[54] China also came in second to the United States in the number of "published, peer reviewed journal articles on nanotech."[55] China's large numbers of students in the United States and elsewhere have undoubtedly fueled her innovation and prolific publication capability.

Russia has realized the potential for nanotechnology only recently and has begun a massive effort to catch up. In 2007, the Russian president signed off on the start of a multibillion dollar effort to build a world class nanotechnology infrastructure by 2015.[56] Russia is trying to overcome the 10 to 15 year head start that the West has had in this vital technology arena. To leverage other expertise, Russia signed a nanotechnology cooperation agreement with China in November 2008, which is sure to kick start its program. Russia has also put in place a massive ramp in planned yearly spending that goes from $730M in 2008 to $1.48B in 2015. There is no doubt Russia wants to be a player in the global nanotechnology market and is posturing to get there quickly.

It is clear from the discussion that all three of these emerging major powers have seen the significant opportunities available with nanotechnology. In addition, each country has invested heavily in building their capabilities to achieve parity or overmatch with US capabilities. The key take-away for US leaders is this is a very competitive field and one that has war-winning implications. The US senior leaders must readily accept the responsibility to understand and maintain a working knowledge of the disparate fields of nanotechnology to enable success in the future. It is clear that others are already doing so. While the US enjoys a significant head start in most of the areas of technology discussed in this article, a few years of low investment in key technologies could change the entire race.

Nanotechnology: Future Implications and the Nano-Enabled Battlefield

[Our adversaries] may develop disruptive technologies in an attempt to offset US advantages. For example, the development and proliferation of anti-access technology and weaponry is worrisome as it can restrict our future freedom of action.

–National Defense Strategy 2008[57]

[a]n officer's effectiveness and chance for success, now and in the future, depend not only on his character, knowledge, and skills, but also, and more than ever before, on his ability to understand the changing environment of conflict.

–General John R. Galvin[58]

Views of the Nanotechnology Future

Senior leaders serve the national interest by preparing for the future. As stated previously, predicting the future is challenging especially when considering the rapid worldwide advance of technology and innovation. Leaders must understand how their outlook of the future can influence their decisionmaking. The following discussion will provide a framework of four disparate views of the future. These views can assist the senior leader in identifying how they or others around them may be predisposed to a certain set of decisions based on their view of the future operating environment.

Joel Garreau, in his book *Radical Evolution*, provides four main scenarios or viewpoints to describe the future.[59] These viewpoints—singularity, heaven, hell, and prevail—are espoused by prominent futurists to describe the coming nano-enabled future and its impact on the human world. Each has strong advocates that espouse their viewpoints with an almost religious fervor. When viewing the future nano-enabled battlefield from each of these perspectives, it is possible to see how the second and third order effects of nanotechnology could play out in the 2035 environment. As senior leaders consider each of these futures, it is not important to completely agree with a particular future, but to see where their own preconceived notions of the future falls within these scenarios. This could lead to discovery of a bias that could then affect decisionmaking.

The first view of the future is called the Singularity and is espoused by Ray Kurzweil.[60] Kurzweil is one of the 21st century's most revered futurists because of his past accuracy and his ability to bring together complex and disparate technological trends and build them into a viable futurescape. In *The Singularity is Near,* Kurzweil provides insight into the acceleration of technologies that are driving this future world. He describes the future when humans and machines will merge in the "Singularity." At that time, "there will be no distinction … between human and machine or between physical and virtual reality."[61] The basis of his argument is the exponential growth curve. In a 2001 article entitled, "The Law of Accelerating Returns," Kurzweil states that the economy will continue to drive the technological advances.

> My projections result from a methodology based on the dynamics underlying the (double) exponential growth of technological processes. The primary force driving technology is economic imperative. The technology is moving toward machines with human level intelligence (and beyond) as the result of millions of small advances, each with their own particular economic justification."[62]

These advances come from across the spectrum of sciences—biology, chemistry, physics, robotics—all converging to eventually allow humans to live forever beyond the singularity. This is not a godlike immortality of the physical being, but is the ability to map, store, and recall all of the information from a person's brain. Or to put it into Kurzweilian terms, today, when the "human hardware dies, the software of our lives dies with it," but in the future, people will be able to store and restore their "mind files" which are their "personalities, skills, memories" to allow their software-based selves to live on forever.[63]

The second view is termed the Heaven scenario. As its name entails, the Heaven scenario sees the coming nano-enabled world in a positive light. Kurzweil is one of the main proponents of this viewpoint. He sees the press toward the singularity as not only inevitable, but wholly a positive thing. From his standpoint, the future is characterized by nearly "unimaginable good things" happening in the world. Through nanotechnology poverty and disease will end while improving the capabilities of the human being. New nano-enabled humans will be more beautiful and wise than they are today and have characters defined by "love, truth, and peace."[64] The predictions of the past that seemed impossible are not only possible, but are "routinely exceeded."[65] The growth of technology, while rapid, remains in control.

The third view is called the Hell scenario and is Heaven's evil twin. The main proponent is, oddly enough, William N. Joy. William Joy is the cofounder of Sun Microsystems. While he agrees that the future will be driven by the same technology espoused by Ray Kurzweil, his prediction of the outcome is exactly the opposite. Bill Joy read some of Kurzweil's early work that described a future where machines gain intelligence and become autonomous thinkers. As these machines also have the ability to self-replicate, they can easily go from being human servants to becoming human masters. From Joy's perspective, the coming evil is inevitable. New threats like nano-enabled bioterrorists and self-replicating nanobots will directly threaten the existence of the human race.

The characteristics of the Hell scenario are that "unimaginably bad things" begin to happen. Large portions of the human race are destroyed along with much of the biosphere. The horrors from "science fiction are routinely exceeded." Technological advances continue to propel both state and nonstate actors against each other as they clamor for a better position in a hostile world. In the Hell scenario, humans will no longer have the control and power to stop the increase of technological advances.

The final view is aptly called the Prevail scenario because it is hopeful yet cautious. The main proponent, Jaron Lanier, is best known for inventing and propelling "virtual reality."[66] According to this viewpoint, the future world is driven by humans, not machines. Humans continue to find a way to surmount seemingly impossible obstacles, even nano-enhanced super viruses. The acceleration of technology may or may not continue on its meteoric rise based on choices humans make to pursue or not pursue a particular technology. Uncertainty is a vital part of this scenario, because it provides the ability for humans to interact with the growth of technology, not sit back and watch it take control over the world. As John Smart, founder and president of Acceleration Studies Foundation, stated in his lecture at the Air War College, humans will still have the "ability to put up roadblocks" to negative change.[67]

A Look at the Nano-Enabled Battlefield

No matter which view of the future one favors, it is obvious that nanotechnology will change the face of warfare. The new environment will require a leader to be more technically aware and able to make decisions faster using machine assistance to collate huge amounts of data into actionable information. The trends toward unmanned systems will continue to grow. The convergence of biomimetics, genetics, robotics, information technology, energy, and artificial intelligence will bring more machines to the battlefield and may obviate the need for human presence on the front lines by 2035. The emergence and spread of robotic vehicles and machine-enhanced humans will dramatically change the decisionmaking challenges for the human leaders. If one considers just the concept of mini unmanned aerial vehicles (UAV) and enhanced humans, they will see the massive changes required in the leadership mindset for the future.

In the world of UAVs, the push will be to make them smaller and stealthier. As they become more pervasive, they will need to be more independent to ensure they can operate in this ever tightening airspace.[68] In the coming decades, micro air vehicles the size of a music box will become nano air vehicles the size of a dragon fly. According to Timothy Coffey and John Montgomery, the smaller the techonology goes the more challenging the physical requirements are going to be. Specifically, "power and propulsion become the dominant components of the weight budget."[69] Beyond that, scientists must solve the difficult challenges of low Reynold's number flight and materials constraints if these UAVs are going to fly. Already several researchers have had success at producing micro air vehicles with some flying vehicles weighing less than an ounce.[70]

While highly-coordinated swarms of nano air vehicles the size of mosquitoes may not be possible until beyond the 2035 horizon, most certainly micro air vehicles will be commonplace on the battlefield.[71] A micro air vehicle could provide a whole host of options for battlefield commanders such as optical, infrared or multispectral reconnaissance, close-in jamming, chemical or biological sensing, and signals collection.[72] The convergence of robotics and nanotechnology into a micro air vehicle will allow many, low-cost sensors in the same air space. As deconfliction algorithms and swarm technology are developed, a single operator will be able to control massive numbers of smaller vehicles. The new battlefield will be able to be surveyed without putting people at risk. Battle damage assessment will be quick and effective. In addition, a disease-ridden failed state could be surveyed with these micro air vehicles to determine what diseases are there and even provide a map of the spread of the disease. These types of capabilities will become more and more available as the cost of the technology decreases.

The cutting edge micro and nano air vehicles will come into the market at prices much lower than today's multimillion dollar Global Hawk, Reaper, and Predator. While each individual mini air vehicle may not match the capability of today's high flying macro UAVs, the combined effect of the swarm will provide a broader, multispectral view of the battlefield with much better resolution because they will be able to fly closer to the earth. Micro air vehicles will become commonplace by 2035—proven, reliable, and pervasive, but being replaced by more powerful, highly advanced, nano air vehicles. While nano air vehicles will initially be more costly than micro air vehicles, they will be but a fraction of the cost per vehicle of today's technology.

The low cost of these vehicles will allow them to be sent into nonpermissive, antiaccess environments and their size and materials characteristics will enable them to operate without fear of easy detection. It will be much less catastrophic if some of these tiny vehicles are lost compared to a loss of one of the large multimillion dollar systems in use today. Their ability to fly close to the ground will also reduce the costs of high tech surveillance camera equipment required today on high flying UAVs. They could also be loaded with nano particle bombs to take precision strike to a whole new level.

It is clear that nano enabled UAVs will bring a host of new capabilities to the battlefield. Along with these capabilities, they bring massive amounts of data that must be collected, collated, and presented in a way that allows the decisionmaker to understand the battlefield and make decisions in a rapid manner. A leader's effectiveness will rest on their ability to leverage technology to enhance their understanding of the battlespace and to tighten their decisionmaking processes. Miniature UAVs are only one small example of what the rapid advancement of technology will bring to the battlespace. Another example that could add even more complexity to the decisionmaking calculus is the emergence of enhanced humans.

The world has shown its tendency to push the edge of human capability in sports, recreation, and beautification. With nanotechnology, the ability to enhance the body will increase dramatically. Instead of drugs and liposuction to enhance performance and beauty, bodies may be sculpted using nano-enhanced bone and muscle structure. What today is a prosthetic to enhance a wounded war veteran's ability to achieve independence, a blind person to regain sight, and an epileptic to gain control of their bodies, could turn into superhuman cyborg-like upgrades. Further, the ability to understand and replicate brain functions in silicon could lead to enhanced access to knowledge and intelligence through embedded or wearable silicon components. With ubiquitous wireless communication, computers will no longer be needed to check the Internet. Instead, information may be directly sent to a nano-enhanced person's neural network.

The implications of nano-enhanced humans and cyborgs on the battlefield are legion. With ubiquitous sensing via the quantum dot-sized sensor nets and nano and micro air vehicles, there will be no place to hide. A person's location will be known or found in very little time. If nano-enhanced soldiers are put into battle against unenhanced soldiers, the fight will be swift and sure defeat for the unenhanced. A nation state or non-nation state possessing this type of army would dominate the world quickly.

The implications of nano-enhancement will be felt across society. In the classroom and business arenas the enhanced versus unenhanced battles will result in *unfair* contests. Will schools segregate or hold contests for the growing disparate populace? Will the gap between the haves and the have-nots generate more conflict? What will a free market system look like when there is a significant performance gap between enhanced and unenhanced people? Is the free market really free when it is controlled by nano-enhanced cyborgs against the will of the unenhanced masses? These questions must challenge leaders to think about the implications of new technology before going down an irreversible path.

The future battlefield will become increasingly complex with undefined boundaries as the Internet enables massing of effects from anywhere in the world. It will likely incorporate state and nonstate actors who have the ability to deliver effects using the same or similar technologies now at the disposal of only the United States. The potential for a disruptive breakthrough in technology is not just available to governments, but also to individuals with technical knowhow, a few low-cost tools, and access to the Internet. According to Michael Paquette, "advances in nanotechnology are also occurring at breakneck speeds." Today, high school students can do what used to be done only by PhDs. "Once nanomaterials are readily available, it is only a matter of time before pieces of information published for a peaceful purpose are used to accomplish something nefarious."[73]

The key challenge for decisionmakers will be tightening the decision loops without falling into decisionmaking traps. As the *playing field* becomes flatter with near peer competitors, the pace of decisionmaking will need to increase to stay ahead of the adversary. As the sensors get smaller and more ubiquitous, the information to make a decision will be even more voluminous than it is today. While victory will still go to the side that can see, understand, and act the quickest to bring forces to bear at the decisive point, the decisionmaker of the future will have vastly more technical complexity to deal with than any time in the past.

Decisionmaking Traps Leading to Technological Failure

In too many cases technological failures and surprises stem from too human characteristics such as self-satisfaction, *disdain for the enemy, obtuseness, and conservatism, or in other words, stupidity and lack of professionalism.*

It must be accepted as a principle that the rifle, effective as it is, cannot replace the effect produced by the speed of the horse, the magnetism of the charge and the terror of cold steel (British cavalry training manual, 1907).

–Azriel Lorber, *Misguided Weapons*, 2002

Making decisions can be hard to do. In the past, many well educated, well meaning leaders have made well intentioned decisions that turned out to be absolutely wrong. While there are a host of reasons for decisionmaking failures, many of these failures could have been avoided if the senior leader had been aware of decisionmaking traps and had developed strategies to avoid them. Decisions in today's complex environment have never been more consequential. A senior leader's ability to make sound decisions about how to shape the future is critical for preparing to fight the nation's wars in 2035. The nano-enhanced battlefield described above will be infinitely more complex than ever before, putting a high premium on good decisionmaking techniques.

Being able to glean the kernels of truth and goodness from the volumes of *chaff* is a skill all leaders must hone. Researchers have found that human brains have subconscious routines or heuristics, to help "cope with the complexity inherent in most decisions."[74] It is these heuristics and mental shortcuts that help us sort the wheat from the chaff, but they can also lead us to make poor, potentially catastrophic decisions.[75] Leaders must find a way to make decisions without falling into a decisionmaking trap. In particular, when considering how to make investments in technology for the future, leaders must be aware of the decisionmaking traps that could lead to technological failure (a concept defined below). While these traps are not new, the ramifications of falling into them are magnified in the rapidly changing nano charged environment. Bad decisions will hurt more. Thus decisionmakers need to be aware of the traps and develop ways to avoid them.

Technological failure, as defined by Azriel Lorber in his book, *Misguided Weapons: Technological Failure and Surprise on the Battlefield*, "involves the lack of comprehension of the effect that certain weapons, or the lack thereof, may have on the conduct of warfare."[76] According to Lorber, a technological failure "may also involve the lack of awareness of the science and technology involved in a particular weapon."[77] One of the most critical aspects of technological failure is that it highlights "people and their attitudes toward the ever-changing world of technology."[78] Lorber makes a clear delineation between technological failure as defined above and other types of failures such as "engineering failure, poor design or workmanship, mechanical breakdowns, [or] shoddy maintenance" as these are failures of the machine itself. Technological failure is not a failure of the machine, it is a distinctively human failure. Lorber provides a cogent list of the root causes of technological failure based on historical examples.[79]

- Conservative thinking, mistrust of new ideas, and inability to adapt to changing environments
- Misunderstanding of the technology involved or its relevance to the battlefield
- Poor management and bad leadership
- Preconceived notions by very important persons, sometimes accompanied by overconfidence and arrogance
- Meddling by higher authority, sometimes because of political ideology

While many will look at this list and see a characteristic of a former boss or colleague, a more important view will be the perspective one takes on this list when looking in the mirror. It is important to remember that most technological failure does not come from unpatriotic, poorly educated, inept leaders. Instead, it stems from upbringing and experience—especially as it pertains to making decisions about technical subject matter.[80] Scientists and engineers tend to understand what is really possible in technical fields and are less prone to technological failure, but senior leaders tend to come from the operational world—not science and technology. Thus, operational senior leaders making the decisions about technological investments tend to lack the requisite knowledge and experience and are more prone to technological failure. This is not to argue that all senior leaders should be scientists and engineers, as this would likely cause operational failures.[81] Instead, the real issue is how to prevent technological failure. Understanding the fundamental decisionmaking traps as they pertain to technological failure is necessary to avoid inadvertently falling into them. This section will cover nine decisionmaking traps that could lead to technological failure. Eight of these traps were identified by Hammond, Keeney, and Raiffa,[82] and one by Lorber. This discussion will entail a brief description of each of the traps along with examples and some suggestions to avoid them.

The Anchoring Trap

The anchoring trap comes from the tendency of people to give more weight to what they hear first. For instance, when getting advice about going to a job interview, most people will advise, "First impressions are very important." Research has shown that what people hear and see first colors their ability to be objective about the information to follow. This trap is especially pernicious when time is short and a decision has to be made quickly. In these situations, the decisionmaker may only have a small amount of information to go on—making the first impression potentially the only impression. More likely than not, the first impression will not tell the whole story and that could lead to a poor decision.

A simple everyday example of this type of trap would be when getting into a bidding process for a major purchase like a car. The first number the buyer provides tells the seller their desire for the vehicle, their willingness to bargain, and sets the zone for negotiation. Similarly, when senior leaders provide information to Congress or give public briefings on acquisition programs, they must take care to ensure the information is correct as Congress and the media can be quite unforgiving. If a senior officer goes to Congress and briefs that they need 183 F-22s to meet their mission requirements for one year, then comes back the next year and briefs that they need 381 F-22s, they had better have exquisite justification for the change, or they have lost credibility. Credibility is easy to lose and very hard to regain.

To avoid the anchoring trap, one needs to consider the sender's and receiver's points of view. From the sender's perspective, they need to package their information to ensure all sides are covered and the information is accurate. Assumptions must be clearly spelled out to the decisionmaker right up front. From the receiver, decisionmaker's perspective, they need to *open the aperture* of their decisionmaking lens. Remember the old adage, "No news is as good or as bad as it seems when you first hear it." Senior leaders must have the patience to get another perspective if at all possible. Taking a *10,000 foot* view of the problem can be helpful. Force yourself to step back away from the details of the situation and try to take the opposing view to see what other possible outcomes could result. Finally, having a trusted advisor who is outside the situation can provide an objective viewpoint.

The Status Quo Trap

The status quo trap is set by the organizational culture and is akin to mental inertia or just plain laziness. If the culture is such that risk taking and effort, despite failure, is rewarded, the status quo trap will not be evident. On the other hand, if employees and leaders are penalized for taking risk and failing, despite their best efforts, the organization will quickly adapt and root out all risk of failure. Large bureaucracies tend to drive a culture where there is one set way to do business and innovation is not looked upon in a positive light. Those that try to *buck the system* are shut down and put back in their place. In fact, one's ability to *toe the line* in some organizations is the measure of merit for promotion and advancement.

Changing course requires action, decisions, and ultimately risk. Risk brings the opportunity for reward and regret. Many decisionmakers, especially those in risk-averse cultures, will choose to forego the chance at a reward to minimize the opportunity for regret. Those that believe they are in an unforgiving, *one mistake* organization will be prone to falling into this trap.

History provides a number of examples of the status quo trap, but the story of Colonel James W. Ripley is one of the best. Colonel Ripley took over as head of the Union's Ordnance Department in 1861. Although Ripley was a career ordnance staff officer and "a good organizer and logistician," he knew next to nothing about the "importance of weapons' technical/tactical performance in the field." Ripley was a stickler for "standardization and economy" in his tightly run supply system, but was against *newfangled* ideas like "breech-loading rifles, Gatling machine guns, [and] observation balloons."[83] Colonel Ripley's bias for the status quo was one of the main frustrations for the Union army. In fact, this stranglehold on technological advancement was still in effect in 1876. When Custer's troops faced Crazy Horse and Sitting Bull, the Union troops had single shot weapons and the Indians had Winchester repeaters.

Senior leaders must have an open mind to newfangled ideas. To avoid the status quo trap they must decentralize decisionmaking and flatten organizations. Decentralization and flattening requires delegating authority and accepting risk. Leaders must set the vision for their organization then delegate their authority until they feel uncomfortable, then delegate a little bit more. Lean towards empowering subordinates to take risk. Expect failure. As leaders, one must realize innovation comes from failure. No one learned to walk without falling down numerous times. Establishing a culture that encourages and rewards risk, within reason, will have the potential to be innovative and leading edge. The culture senior leaders establish in their organization affects the grooming of those rising through the ranks. If they choose to leave a legacy of fear of failure, they will produce a generation of risk-averse bureaucrats who cannot meet the challenges of the fast-paced future environment filled with newfangled technologies.

The Sunk-Cost Trap

The sunk-cost trap is one that causes leaders to want to keep *throwing good money after bad*. When poor decisions of the past lead to a project failure and all logic suggests the project should be canceled, this trap causes one to argue against logic. The more money that has been spent on a project, the more difficult it is to terminate it. Instead of cutting losses, decisionmakers tend to want to *increase its functionality* and spend more money to keep from acknowledging failure.

In 1866, the Prussians handily defeated a nearly equal-sized force of Austrians at Sardowa. While there were multiple reasons the Prussians were victorious, one of the main reasons cited in an 1868 account of the battle was that the Prussians had a decisive technological advantage.[84] Most of the 20,000 Prussian troops were equipped with Dreyse needle guns, while the Austrians had muzzle loaders. The needle guns fired six rounds a minute versus only two per minute for the muzzle loaders. The fact that the Prussians had a technological advantage was not a technological failure, but *why* they had the advantage gets to the heart of technological failure.

Nikolous von Dreyse developed the needle gun around 1838 and demonstrated it for the Prussians. Seeing the speed at which it could fire and the fact that the soldier could fire from the safer prone position was enough to get the Prussians to purchase the rifle right away. In 1851, the Austrians got a similar sales pitch and chose not to purchase the needle gun. In their opinion the rapid fire aspect of the weapon would exhaust the ammunition supply. Even more important to their decision was they had just sunk a significant investment into retooling their musket factory "for more efficient production."[85] Thus the sunk-costs of older technology outweighed the opportunity to gain a leap in technology and that resulted in the Austrian defeat at Sardowa 15 years later.

Senior leaders must be able to maintain big picture objectivity. To avoid the sunk-cost trap, they must establish objective measures of success and failure at the outset of a proposed acquisition or project and then have the courage to act as required. To gain an objective viewpoint, have a disinterested third party take a look at the situation at regular intervals to provide an unemotional evaluation. Audit agencies are good resources to call on for this type of perspective. Money and time spent on a project in the past is just that—history. To make an objective decision about the current health of an acquisition or project, leaders must disregard sunk-costs and look solely at the requirements versus the solution to determine whether the need justifies further expenditures or if a different path is warranted.

The Confirming-Evidence Trap

The confirming-evidence trap is particularly insidious as it plays into one's biases. It causes one to see supporting evidence for positions they want even when it is not there and to disregard evidence that counters what they want, despite its relevance. This trap can also be set by any or all of the three previous traps. For instance, if the first impression of a person is negative, the tendency is to find evidence of more negative things despite the person's best efforts to the contrary. Similarly, if one is convinced the status quo is the *right* way of doing business, they will find evidence to confirm their convictions even if there is a more efficient and effective way to do business. Finally, if one is a program manager for a failing program, his or her reputation and livelihood could be wrapped up in sustaining the program despite its faults. The loss of objectivity could cause one to seek evidence to confirm the positive health of their program despite objective measures to the contrary.

Any one of the examples above will also work for this type of trap. For instance, Colonel Ripley would most likely not have established an objective set of measures for the tactical success of the weapons he was purchasing versus those he denied. Instead, his measures of merit were likely logistical effectiveness and cost efficiency. Therefore, when he sent his reports to his superiors, everything would have shown *green* and healthy despite the lack of support to the Union troops.

To avoid the confirming-evidence trap leaders must maintain objectivity. To do this, they can employ trusted third parties to provide an objective assessment based on facts outside their biases. They need to establish a healthy organizational climate that allows for difference of opinion and disagreement. To foster this type of environment they need to be able to check their motives objectively through self-analysis or through the use of trusted agents. Further, they need to learn how to ask questions that do not drive a particular answer. This is hard to do as people are hardwired to play to their own biases, but they must fight the temptation. The use of an unassociated facilitator to run a potentially contentious meeting can be helpful. Meeting at an off-site location in casual clothing can also be helpful to increase objectivity and trust within an organization.

The Framing Trap

The framing trap stems from the fact that how a problem is stated can and will drive the solution to the problem. The solution can be biased on purpose or subconsciously. This type of trap is readily evident in how contracts are written or how new personnel is hired. If one has a particular solution or company in mind when writing a contract for bids, it could provide a distinct advantage to the desired outcome. In addition, if one already has a person in mind to fill a particular job, they can bias the requirements to ensure that particular person comes out on top of the rating criteria. Further, if a leader is from a particular Service component, they will likely take a view of the battlefield from their Service's perspective.

In March 2002, the Army planned its first conventional operation in the Shahi-Kot Valley in Afghanistan named Operation Anaconda.[86] The goal was to take out a concentration of Taliban and Al-Qaeda fighters operating in the valley. The mission was given to the Army, who planned it as a ground centric operation. The Army planners chose not to involve the Air Force in their operational planning until after it was too late to effectively use the Air Force assets. As a result, the action was a dismal example of the lack of Joint operations and resulted in many of the enemy escaping from the valley to fight another day.

In this example, the problem was given to the Army who framed it as a ground offensive. If it had been framed as a Joint fight by air and ground forces, the planning efforts would have been inherently more Joint and the results would have been much more coordinated and smoothly executed.

If a leader wants to solve a problem without unnecessarily biasing the solution, they must provide a neutral problem statement. They must establish objectives and the end state, and then let the problem solvers do their job. For instance, if they are seeking to buy a weapon system to carry out a mission, they must be careful to provide only the objectives and key performance parameters. If they use the words "ground vehicle," they have then biased the solution against anything from an air or water perspective. Further, if they state that the vehicle must be manned, then they have disregarded all unmanned capabilities. While establishing clear requirements and boundary criteria, leaders must guard against inadvertently limiting the range of solutions based on their personal biases. Using a third party observer or even having their proposed problem statement checked by other experts in the field is an excellent check and balance that will lead to better outcomes.

The framing trap also works in reverse. As decisionmakers consider a range of proposed solutions to a particular problem, it is helpful to look for how the problem statement was framed. Look for biases and predisposed solutions. Many times leaders find that a viable solution set was not considered due to how the problem was originally framed.

The Overconfidence Trap

The overconfidence trap causes leaders to take an overly positive view of their leadership prowess and forecasting acumen. This trap is inherent in organizations known for their success and longevity. Over time, success can build up a sense of superiority and overconfidence that can lead to prideful decisionmaking. The Bible provides an apt adage to consider: "Pride goes before destruction and haughtiness before a fall." When leaders consider themselves impervious to error, they have fallen into the overconfidence trap.

The Battle of Crécy in 1346 is an early, but classic, example of technological failure due to overconfidence (or arrogance). The key take-away from this battle is how an English force primarily made up of trained peasant infantry could achieve a resounding victory over the French forces primarily made up of upper class cavalry when the French forces outnumbered the English forces by a margin of at least two to one with some accounts suggesting a six to one advantage.[87]

One of the key differences was their weaponry. The French were armed with crossbows and the overmatched English were armed with longbows. A seemingly minor difference in technology, but it was a major difference in capability. The simplistic longbow could be made in a few hours, but could be fired four to five times faster than the crossbow and was lethal at much greater range.[88]

What makes this battle a technological failure by the French is not that they lost to a much smaller British force armed with longbows, but that this wasn't the first battle where they were beaten by a smaller British force armed with longbows. The battle of Flanders in 1337 had a similar result to that of Crécy and for the same basic reason. The French were men of nobility and considered the British peasants armed with longbows as inferior. They kept this overconfident attitude despite being soundly defeated at Flanders, Crécy, and later at Sluis in 1340, Poitiers in 1356, and finally Agincourt in 1415 all at the hand of the peasant longbowmen.[89]

The arrogance and resulting inability of the French nobility to think of the English as more than a peasant army, colored their decision to not transform their army's weaponry and tactics. The history of that decision is written in the blood of the thousands of French fighters on the battlefields of the Hundred Year's War.

To avoid the overconfidence trap requires humble introspection on the part of the decisionmaker. Senior leaders must be open to criticism. Establishing an organizational structure where one can get unfettered feedback from subordinates, peers, and superiors will provide the feedback necessary to maintain a level view. These same feedback sources will provide good venues for discovering issues dealing with one's organizational construct, but the climate must be one that is open to criticism. An external audit by a third party is useful for determining if an organization's confidence is well placed. Finally, developing a series of advisors and trusted agents within an organization and outside of it will ensure decisionmakers get the unvarnished truth.

The Prudence Trap

The prudence trap is a characteristic of risk adverse organizations. These organizations want to *play it safe* and avoid making mistakes. They also tend to be ploddingly slow decisionmakers. Large bureaucracies tend to fall into this trap due to their desire to maintain the status quo. They tend to shun innovation and quell disruptive behavior. The inertia from these types of organizations not only makes them difficult to change, it can make them cautious to the point of irrelevance.

Too often bureaucracy within the Pentagon is guilty of this trap. The entire process of staffing a proposed change through the myriad of offices to reach a decisionmaker tends to remove the energy for change. As radical, edgy proposals go through the chain of bureaucracy, their sharp edges get rounded off and polished as each layer tries its best to put its own personal spin on the document. All too often the proposal that ends up on the decisionmaker's desk is a much watered down instrument for change. While not all offices work like this, the overall effect of such a large bureaucracy is to maintain the status quo with minor adjustments on the fringes.

To avoid the prudence trap begins with thinking differently about change. The top of the organization must start the process because the bureaucracy is set up to maintain a steady state condition. The first step is to delayer the decisionmaking process. The more horizontal an organization is, the more able it is to change and adapt. The second step is to delegate as low in the organization as possible. Get the lowest level supervisors actively making decisions and getting involved. Third, accept more innovation risk. Leaders need to trust their people and reward disruptive innovation. If they stifle change and disruptive influences, their organizations will quickly learn "not to make that mistake again." Be prepared to hear the unvarnished truth. Minimize the number of touches on a document coming through the process for signature. Find ways to remove or consolidate the reviewers so there is not an endless list of folks that need to see a document on the way up to the boss. While prudence can be a good thing, it can also cause one to fail as they let golden opportunities pass by while the bureaucracy churns.

The Recall Ability Trap

The recall ability trap causes a leader to put more emphasis on recent events than history—because that is freshest in their minds. In contrast to countries like India, China, England, and Japan that have fastidiously maintained detailed paper filing systems, America is very poor at maintaining corporate memory. On the one hand, this provides the opportunity for advancement unfettered by historical precedent; on the other hand it can lead to shortsighted decisionmaking.

For instance, the short two-year military command tours drive a constant turnover of corporate memory at the organizational command level. This provides a level of churn in an organization that can cause unhealthy and poor decisionmaking. As each new leader takes over an organization with the desire to leave his or her mark, the organization is unable to maintain a steady course. Officer assignments for senior field grade officers tend to be two years or less. Wing command tours in Air Mobility Command are now routinely less than 18 months. This type of rapid turnover prevents organizations from maintaining momentum. Further it can detract from strategic planning as everyone must shift priorities as each new commander comes to roost.

To prevent the recall ability trap requires a major investment in knowledge management, a reduction in turbulence, and a reinvestment in long term planning. As organizations move to paperless systems, the only records they will have will be electronic. The Department of Defense has made a halfhearted attempt to develop electronic filing systems, but to little avail. With the removal of the administrative career field, it comes down to the motivation of the individual to track their own history—many do not. Capturing knowledge at every level to develop an accurate history and making this knowledge readily accessible is necessary to inform future leaders and look for long-term trends.

The Mirror Imaging Trap

The mirror imaging trap is when the analyst or decisionmaker projects his or her values or culture on others. The Battle of Britain provides an example of this trap. The British had developed their famous Chain Home string of coastal radar sites to warn of incoming German aircraft. These radar dishes were huge—360 feet high and very visible.[90] The Germans noticed these massive dishes and were curious as to what they were, so in 1939 they sent a zeppelin loaded with radio receivers to investigate. After several hours of monitoring, they heard nothing and concluded the huge dishes had to be something other than radar.

This failure to recognize these radar towers was due to mirror imaging. In 1939, the Germans were more technically advanced in their development of radar. They had developed the Wurzburg radar that operated at wavelengths on the order of fifty centimeters.[91] The less advanced British radars used wavelengths of over a meter. Thus, even though the chief of the Luftwaffe's signal section, Major General Wolfgang Martini, was onboard the zeppelin, they did not hear because they did not listen to the right frequencies. The Germans only listened to the frequencies that they used. Had the Germans understood the advantage these radars gave the British, they could have put in a sustained effort to destroy them and potentially changed the outcome of the Battle of Britain.

The mirror imaging trap is challenging to avoid completely as it is so easy to project one's own values and capabilities on others. To avoid the mirror imaging trap one needs to first realize they are prone to this type of trap. Then, the decisionmaker must willingly accept peer review of their analysis and projections. As a senior leader, establish an organizational climate where peer review of consequential analysis and future projections is the norm. Leaders must check egos at the front door and be open to criticism and encourage differences of opinion because only then will true innovation take place.

Avoiding the traps described above is a significant challenge. Most leaders will not be able to do this naturally as all leaders have biases toward one or more of the traps described above. The key is to understand where these biases lie and then develop a strategy to avoid the traps. The future environment will make avoiding these traps even more challenging as it is always changing and more complex.

Recommendations for Disaster-Proofing Senior Leadership

Leaders must be prepared to think differently if they are to make the right decisions to prepare for the challenges of 2035. While 2035 may seem like a long way into the future, the generals who will lead the Service components are in the Service today and the President of the United States is already in the population. They are gaining the knowledge and experience that will shape their decisions in that future battlefield. What tools should be provided to them? What experiences and thought patterns must they have to be successful in the future environment?

To make the senior leaders of tomorrow successful, three things must be done now: prepare them for success, organize for success, and invest for success. The rest of this article will discuss these three key elements and how they are imperative for the prevention of technological failure and the achievement of success in the future battlefield.

Prepare Leaders for Success

From the very beginning of their experience in the military, the leaders of tomorrow must be prepared to understand and embrace technology and change. This means staying informed about advances in technology. Leaders must be in a continual mode of reading and staying updated in critical areas. Broadening tours to the civilian or military research facilities should be encouraged for future leaders. In addition, since time is a limiting factor, tools such as automatic electronic updates on technology advancements and book summaries[92] should be provided to all levels of the Air Force—not just general officers. The younger generation coming into the military today is already tech savvy and willing to try nearly anything to "see how it works." The Services need to provide the tools to broaden their knowledge base and nurture that innovative energy and drive in a mode commensurate with the techno-savvy capabilities of this new generation. The senior leaders of tomorrow must have access to the tools to keep themselves on the cutting edge and maintain that innovative spirit.

Fostering innovation is easier said than done. Innovation involves risk. In fact, to gain the correct organizational environment, risk-taking must be rewarded. Unfortunately in most cases, the Air Force has done just the opposite. Safety has been emphasized to the point of making people risk averse. Gone are the days of Jimmy Doolittle and Carl Spaatz who lost numerous airplanes trying new things. At the time, this was considered the cost of doing business because innovation was part of the job of every Airman. It was part of the culture of the Air Force and it allowed the Air Force to incorporate new technological advances rapidly.

The innovation spirit must be brought back. One way to do this is by giving people the freedom to fail. While there is a clear distinction between a mistake and a crime, trying to define good failure and bad failure is always going to be a leader's judgment call. One example of fostering innovation would be to develop a leadership *playground*. This can be done by making leadership reaction courses and obstacle courses readily available at the base level. With easily accessible training areas, teams of lieutenants, colonels, sergeants, and Airmen can build teamwork and keep their minds fresh by periodically working through multiple scenarios. By using cutting edge virtual technology to develop training environments, cross-function teams could rapidly devise new challenges in a virtual reality environment. Much like a flight simulator or a multiplayer gaming scenario, the same type leadership simulation experiences could be brought to the general forces. By practicing leadership decisionmaking at all levels of the organization and in complex scenarios, leaders will be better able to enter new situations with confidence. They will be allowed to fail and recover to find a better way without fear of retribution. This can go a long way to developing better decisionmaking skills.

One of the most effective methods of preventing technological failure is to remain humble by listening to others. Why is this so important? Considering the examples of technological failure discussed in the previous section, most of them dealt with some sort of pride issue—either the senior leader was overconfident of his or her own abilities or disdainful of those of the enemy. Leaders failed when they got stuck on their own ideas being the best ideas and not being willing to consider the views of others. Finally, leaders that project their strengths and weaknesses on the adversary are also failing because of arrogance and pride. This type of arrogance and pride can infect the entire organization and develop organizational biases that will result in a future of poor decisionmaking. As senior leaders demonstrate and mentor leadership for their younger officers, they need to be mindful that they are providing the shaping experiences that will last in the minds and hearts of those airmen for many years. These experiences then can translate into a decisionmaking framework that will lead to successful or disastrous decisionmaking.

Organize for Success

Organizations are a reflection of the leader and the bureaucracy that formed them. The organizational structure can install artificial barriers to innovation and ultimately barriers to success. Take for instance the A-staffs at the Pentagon. Each staff is a *cylinder of excellence* that maintains itself through the requirement that many staff packages must pass through their hallowed halls before getting finalized and sent to the mutual boss. This type of hierarchical structure found in these organizations stifles innovation on purpose. There is a built-in bias against changing the status quo and many live in the prudence trap. The leaders of these organizations are seldom aware they are getting watered-down packages without the author's original thoughts in any recognizable form.

To change this construct, mobile, cross-functional teams must be created. The team members must *live* with the organization that needs them most of the time and be available to others who need their specific expertise. To truly expand the ability to make good decisions every time, leaders must build cross *cognitive* teams—teams made up of people who do not think like they do.

Scott Page, in his book, *The Difference*, discovered that teams made up of diverse cognition actually improved problem solving capability more than any other kind of diversity.[93] Through the use of virtual reality-based communication tools, they need to be able to tap directly into the warfighters in the field and every functional area needing representation. There should almost never be a meeting that happens with only people from a single cylinder.

Virtual reality is the way business will be conducted in the next decade. With the advance of sensors that can provide full body exposure to the environment, *being there* just got a lot less expensive. Already the military is experimenting with the use of avatars for training, meetings, and advertisement. Soon, the avatars will be connected via virtual reality to their human and the humans will experience nearly everything that they would in a person-to-person meeting. This technology can be utilized for training, experiencing, and building better decisionmakers.

Decisionmakers trained in a virtual environment will have the ability to run through a complex set of scenarios and find the best way to solve the problems. These decisionmakers would have the benefit of a database of lessons learned and best practices that could be brought up as possible solution sets. While no simulation can perfectly mimic real life, virtual reality will come closer and closer to real life and will provide a distinct advantage to the decisionmakers of the future. Decisionmaking traps could be a thing of the past if leaders are adequately trained in the right behaviors through simulations and organized for success.

Invest for Success

Rapid reaction will be critical to survival in the 2035 battlefield. For instance, if a bioterror attack takes place, the ability to sense, decide, and act with incredible speed could be the difference between victory and defeat. Leadership must not only be able to make decisions quickly, they must have access to a viable set of alternative actions to solve the situation. In the case of a bioterror attack or many other rapidly multiplying challenges, the solution may not be readily available. At that point, the leader must call on the acquisition system to deliver a solution. To enable this, they need an acquisition system primed to respond to threats of all kinds. Super-empowered individuals with the capability to coordinate and mass effects could strike using nano-based weapons and cyber technology to threaten America's ability to respond. A senior leaders' ability to develop a response in time to eliminate or mitigate the threats may determine whether America remains a free country or not. The gravity of this issue means America, and specifically the Department of Defense, must invest in research and development to maintain a broad spectrum of capability in the uncertain future and invest in consequence management capability to respond quickly to surprises.

As budgets tighten, it is normal to focus more on applied science versus basic research. Said another way, if one has to make a choice between supporting the current war and supporting a possible future war, the current war funding will normally win. While logical, this type of decisionmaking has serious ramifications for the future. As the senior leaders of tomorrow reach into their bag of technology-based tools to counter emerging threats, the tools they have will be those developed by basic research today. If the research today is focused on near-term projects, the tool bag of the future could be filled with a set of ineffective, obsolete instruments.

Resisting the urge to unbalance defense laboratory research toward applied research will ensure a broad spectrum of responses for future threats. Defense labs must maintain a strong presence in niche technologies enabled by quantum computing and nanotechnology that may not be profitable for private laboratories to fund. These niche technologies just may provide the needed capability for winning wars. While the US can leverage private and university research capabilities to expand its applied research portfolio, the defense lab structure is many times the only source for war winning, defense-specific basic research. With a strong basic research backbone balanced with a strong applied research network, the US can ensure it maintains the edge against all enemies, foreign and domestic.

The name of the game in 2035 will be consequence management. With the spread of nanotechnology to nearly every corner of the world, the playing field will be much more leveled between the US and its adversaries. The US must have leaders that can think as its adversaries do to understand their goals and desires and be ready for any contingency. While 100 percent preparedness is a good goal, these leaders must also plan for surprise from innovative adversaries as the US will surely face threats no one has seen before.

An example of consequence management in action would be in combating the dark side of nanotechnology-based drug delivery. If it is possible to deliver a dose of cure right to the malignant cells as the nanobot concept goes, a nefarious group could also use the same technology to target other cell characteristics as well. They could surely isolate a portion of the molecular makeup that defines a particular part of the human race. In a hell-like scenario, a bioterrorist could unleash a targeted attack on an entire segment of the human race. The capability of the US to understand the problem, find a solution, and respond quickly through effective consequence management methods could mean life or death for many. In instances such as these, the US cannot afford long acquisition and development timelines. The US must act—and act fast.

Leaders looking to invest in the future not only need to determine the types of investment decisions to make, but also the optimal timing for those investments. Knowing that every choice in funding will force a choice to not fund something else, leaders must focus on leveraging high pay-off investments. High pay-off investments are those that will provide the most bang for the buck in the future. Looking back to the exponential curve discussed in the first section, it is evident that the best time to invest to achieve the maximum effect is early in the process. Achieving a one to two percent increase in slope on the early part of the exponential growth curve will mean a massive increase in capability as the technology matures. As an example, molecular computing and quantum encryption are on the early part of the exponential growth curve today and both of these technologies will have world domination implications for the actor that achieves the technology first.

In the world of 2035, molecular computing and quantum encryption could have the same effect as the first atomic bomb had on the world—possibly even more of an effect. The first quantum computers will be used for niche applications like crunching massive amounts of data in a very short amount of time. Their massive speed and limited spectrum of focus would be perfect for cracking encryption codes that protect the world's computer networks. The security implications are enormous and far reaching, especially if the US is not the first country with this technology. Scientists estimate a quantum computer the size of a thumb nail will have the same amount of communication power as all the computers that have ever been built. With that type of computing power, the possessor could crack any current encryption code instantly and the owner could hold the financial, military, and commercial network capabilities hostage. In the hands of a super-empowered individual, this technology could change the face of war and terrorism. Without a doubt, the United States must be the one to conquer this challenge. The funding needs to be applied and the intellectual capital spent to ensure that the US has the first quantum computer.

The second example of a high pay-off area for investment is in quantum encryption. This little understood concept is going to be the risk-mitigating technology for the foreseeable future. This technology will provide encryption security that even a quantum computer cannot break into. With the entire world economy tied to the health of the American financial and network infrastructure, the United States must be the first to achieve this technology. Without assured access the market could completely destabilize—creating a worldwide crisis that makes 2008 look very calm. Quantum encryption is a war-winning (or losing) technology and the United States must have this particular technology first.

These two examples of high pay-off investments are not the only investments for the future, but they are ones that illustrate the concept of timing and impact. As senior leaders look towards preparing for the future, they must have their eyes open for these types of high pay-off investments to ensure the future toolkits are filled with war winning capability. To grasp the magnitude of the impact of these technologies first requires an interest in learning about technology and then a method to stay informed. Future decisionmakers must purposely seek to stay engaged in technology advances to fully understand the future battlefield environment if they are to make good investment decisions.

Conclusions

Capable, well-intentioned leaders often make poor decisions that lead to technological failure on the battlefield. Sometimes it is a result of a failure to understand technology or its relevance to the battlefield. Other times, poor decisions are made because of a mindset or organizational structure that leads into a decisionmaking trap. As technology accelerates at an exponential rate, the consequences of poor decisionmaking become amplified and more far reaching. It is imperative to do everything possible to prepare leaders, set up diverse organizations, and invest resources wisely to prevent technological failure in the future. The steps taken now will have an escalating impact on the ability to succeed in the battlefield scenarios of 2035 and beyond.

The first step to preventing technological failure is to keep leaders informed about developing technologies through self-study. They must become familiar with terms associated with the technologies and understand the implications of concepts such as nanotechnology, quantum computing, biomimetics, artificial intelligence, and nanobots.

Leaders must also think differently. Instead of thinking linearly and locally, they must think exponentially and globally. They must understand how the new flattened world gives rise to threats and opportunities across the spectrum from state actors to empowered individuals. Further, they must understand how the exponential growth in technology and globalization will impact the future battlespace. With this foundation, they must then look inward to personal biases that can lead to decisionmaking failures.

Leaders must be aware of the decisionmaking traps and understand which of them they are most prone to fall into. Being aware of the traps is the first step to avoiding them.

- The Anchoring Trap: Be aware that first impressions rarely tell the whole story. Step back and consider all sides of the situation before making a decision. Call on a third party for advice.
- The Status Quo Trap: Establish a culture that encourages innovation without fear of failure. Encourage newfangled ideas.
- The Sunk Cost Trap: Maintain an objective viewpoint. Call on a third party to gain an outside evaluation.
- The Confirming-Evidence Trap: Understand personal biases. Employ a trusted agent to gain an objective outsider viewpoint. Foster a culture that allows for airing differences of opinion.
- The Framing Trap: Carefully evaluate problem statements for biases that inadvertently limit potential solutions. Gain an objective view of the problem statement from a disinterested third party.
- The Overconfidence Trap: Develop a habit of objective self-assessment. Be open to criticism. Foster opportunities to receive unfettered feedback from subordinates, peers, and superiors.
- The Prudence Trap: De-layer decisionmaking. Empower and entrust leaders at the lowest levels to innovate. Seek out the *unvarnished* truth.
- The Recall Ability Trap: Capture knowledge at every level and develop a readily accessible database of historical knowledge and lessons learned.
- The Mirror Imaging Trap: Understand personal biases. Check egos at the front door. Establish system of peer review for consequential analysis and future projections.

Organizations must prepare leaders to make good decisions by building leadership training areas either physically or in virtual reality training environments. These areas will provide leaders the freedom to innovate, fail, and correct multiple times at low cost.

Institutions have to organize for success by developing decision support structured organizations. These organizations must bring together, physically or virtually, a cognitively diverse team to solve complex problems. The more complex the problem, the more important it is to have a team of cognitively diverse experts brought together to solve it.

Finally, the Services must invest for success by funding high pay-off investments at the optimum time near the beginning of the exponential growth curve to maximize every dollar spent. These investments must encompass the technologies that will have the greatest impact on the coming battlefield environment. This will ensure future leaders have the tools they need to fight and win the wars of the future.

The challenge of avoiding technological failure and decisionmaking traps in the future intensifies as the environment becomes more complex and the processes of change continue to accelerate. Staying current on future trends requires constant vigilance. Leaders must proactively face the future and its challenges, and seek the knowledge to prepare for it. The implications of not doing so could prove disastrous. The hope for the future lies in having adequately prepared leaders who understand their own shortcomings and the traps they are prone to, organizations that are set up for cognitive and structural diversity, and the right investments of our current resources to ensure the possession of the necessary technologies and weapons to wage war successfully in the nano-battlefields of tomorrow.

Notes

1. Victor E. Borisenko and Stefano Ossicini, *What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology*, KGaA, Weinheim: Wiley-VCH Verlag GmbH, 197.
2. According to the National Nanotechnology Initiative Website, http://www.nano.gov/nanotech-101/what/nano-size, a sheet of paper is about 100,000 nanometers thick, a human hair is 80,000 nanometers wide, and a strand of human DNA is 2.5 nanometers in diameter. To get the number of microns, simply divide by a thousand…for example, a sheet of paper is about 100 microns thick.
3. Lynn E. Foster, *Nanotechnology: Science, Innovation, and Opportunity,* Upper Saddle River, New Jersey: Prentice Hall, 2006, 37-40. Describes the limits of the current top down lithographic paradigm for achieving consistently smaller pathways. A couple examples are cost and temperature of manufacturing as well as quantum mechanical tunneling that occurs when the electronic pathways get closer.
4. Ray Kurzweil, *The Singularity is Near: When Humans Transcend Biology*, New York, New York: Penguin Books, 2005.
5. A decade later, the rate of acceleration was actually doubling at a rate of approximately 18 months, exceeding even Moore's prediction.
6. Although Moore's Law has proven true to this point, some suggest it is coming to an end. At some point, they say, we will reach the limit of the dielectric constant for silicon such that transistors simply cannot be put any closer together without the resistive walls made of fewer and fewer atom layers eventually leaking current between transistors. These skeptics see us approaching the limit of the current manufacturing capability around the year 2017. Others believe that Moore's Law will continue to hold true. They comment that its end has been predicted many times in the past and every time a critical breakthrough has come along to keep technology on the exponential slope. These people cite current research using Hafnium whose dielectric constant will allow a closer packing of components than with silicon. Research being done at Hewlett Packard Labs has led to a new technological breakthrough called the "memristor." They have shown that a single memristor can do the work of multiple transistors and thereby shrink some circuits by a factor of ten. Thus, there seems to be additional life to Moore's Law.
7. Lynn E. Foster, *Nanotechnology: Science, Innovation, and Opportunity,* Upper Saddle River, New Jersey: Prentice Hall, 2006, 38.
8. Foster, xiii.
9. Foster, xiii.
10. Foster, 41.
11. The Scanning Tunneling Microscope (STM) and the Atomic Force Microscope (AFM) are used to move atoms around with atomically thin needle tips. See Foster, *Nanotechnology*, 43, 211. New technology is spawned everyday that will allow more and more capability to manipulate atoms. STM and AFM are still very viable technologies. The purpose of this article is to explain the exponential nature of technology growth and its implications on the future leadership environment.
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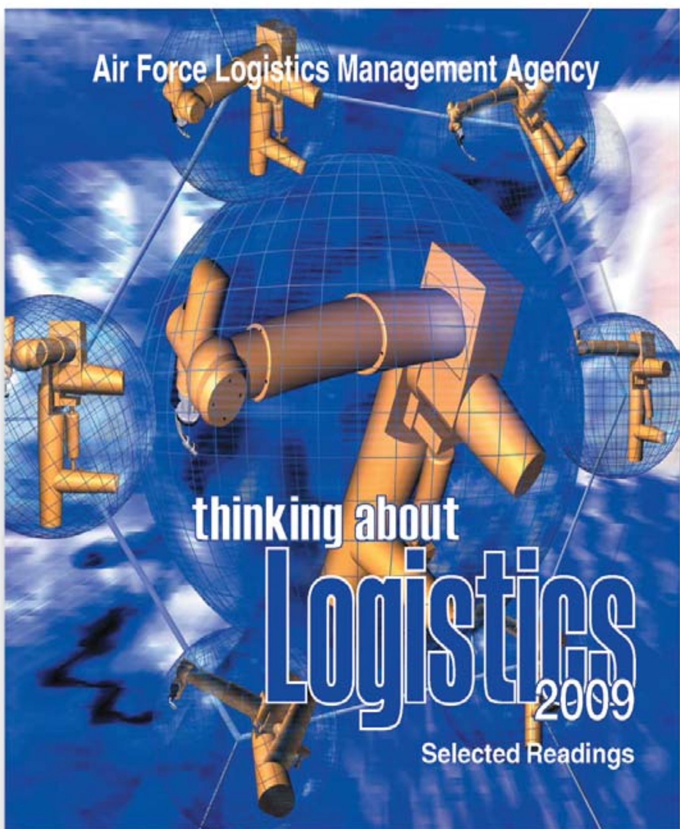
***Colonel Allan E. Day** is currently the Commander of the 309th Maintenance Wing, Hill Air Force Base, Utah. At the time of the writing of this article, he was a student at the Air War College, Air University, Maxwell Air Force Base, Alabama.*



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