Technology and Command

Implications for Military Operations in the Twenty-first Century

William B. McClure, Lt Colonel, USAF

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Center for Strategy and Technology
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Abstract

The introduction of advanced technologies into the military, which is known as the “revolution in military affairs,” is producing an opportunity for significant changes in the American military's paradigm for command and control. The future battlespace will require commanders to operate more efficiently and at a higher operations tempo, so that commanders will be able to use the advantages of dominant battlespace awareness to enhance what is known as “command-by-intent.” But the more likely outcome is a return to command-by-direction. A potential consequence of this change is that significant command functions will be made by machines that act, not as an assistant, but as the decision maker and executor — which is known as the machine commander. However, the current U.S. military doctrine is inconsistent about the admissibility of such an entity, even though technological developments are on the threshold of delivering the components for constructing the first-generation machine commander. Furthermore, the same infrastructure that assists the traditional human commander creates a framework for using a machine commander. While resistance to this technology is expected, this is the proper time to examine the implications of a machine commander for military operations in the future.

I. Introduction

The twentieth century has seen mankind conquer the atmosphere in regions adjacent to the earth through powered flight, then into near-earth space with rockets, and finally beyond the limits of our solar system with deep space probes. It seems fitting that, having mastered the final spatial dimension, we find ourselves at the brink of the twenty-first century preparing to embark upon a journey to master the fourth dimension — time.

Time has long been recognized as a critical dimension to warfare, which is equal in importance to distance and altitude. Time is formalized in the current U.S. Joint Doctrine through the "operational art elements" of timing and tempo.[i] These elements, founded in time, are to be combined in a manner that best exploits the capabilities of friendly units and inhibits the enemy.[ii] The advantages of controlling time are also implicit in the increased speed of communication and the velocities of weapons.

According to the current American doctrine, *Joint Vision 2010*, forces will operate in an increasingly lethal battlespace that places greater reliance on our ability to function at a higher tempo. Controlling and, when beneficial, accelerating the operational tempo will complicate enemy targeting and reduce the effectiveness of weapons of mass destruction when U.S. forces are operating on the defensive. When conducting offensive military operations, controlling the operational tempo enables U.S. forces to seize and maintain the initiative during offensive operations.[iii] Higher tempo, in turn, will stress the commander's ability to coordinate and synchronize forces in ways that will help the U.S. military achieve its military objectives as effectively and efficiently as possible.

The challenges for the commander of increased tempo will be exacerbated by the growing complexity of the battlefield, which is an extension of Clausewitz's concept of friction to the concept of "hyperfriction." It is likely that the integration of weapons, soldiers, sensors, and communications links will produce revolutionary advances in military effectiveness. But the robustness of these systems will be tested through battlefield attrition and logistics problems. Any future enemy is likely to challenge U.S. conventional military strength through asymmetric means, including the use of weapons of mass destruction. And the U.S. aversion to casualties will weigh heavily on the commander's mind.

Finally, the ability to be connected in real-time with the senior leadership, including the National Command Authorities, Joint Chiefs of Staff, or theater Commander in Chief, creates the possibility that the military commander's duties will me micromanaged. This problem may extend to non-governmental organizations with which the commander is expected to coordinate, and do so while operating at a rapid operational tempo and retaining the initiative. The key factor is for the commander to take control of the battlespace by embracing the coming revolution in military affairs, whereby advanced technologies that are incorporated within new processes and executed by new organizational structures will make existing tactics and weapons obsolete.[iv]

Perhaps the greatest implication of the coming "revolution" is to put the current command paradigm of the U.S. military in jeopardy. Until now, the pace of war has been such that a commander, with staff assistance, could gather and process the essential information to develop and execute command decisions. The speed of mental and organizational activity did not substantially constrain the conduct of the war.[v] But the speed, range, lethality, and tempo of future combat will significantly shorten the time available to the commander to the point where demands for rapid decisions will far outpace the capability of the human brain.[vi]

Psychological studies illustrate that the amount of information that the human mind is capable of receiving, processing, remembering, and acting upon is quite limited.[vii] While there is some advantage to aggregating and organizing information, the benefits from condensing information also have limitations, usually in the form of additional processing time and the loss of detail that occurs with generalization. Given these constraints on the "information bandwidth" of the human mind, the tempo of the battlefield may eclipse the observe-orient-decide-act (OODA) pace of the commander's decision cycle.[viii]

In this case, the concept of dominant battlespace awareness may simply become "paralyzing information overload." If so, simply modernizing the current command and control paradigm, with its dependence on the human commander and his staff, represents a significant risk for the high-tempo battlefield of the future. An alternative system must be considered. It is conceivable that U.S. military and commercial investments in technology may offer a solution in machine-based decision-making in which machines automatically make and execute military command decisions in ways that free humans from intervention.

The accelerating pace of technology, the current focus on the importance and enabling potential of information, and the resources that will be invested in the U.S. military create an opportunity for introducing machine-based command. The time is rapidly approaching when industry will propose a *machina sapiens* (thinking machine) for the military.[ix] Indeed, we may already be building our own *machina sapiens* and have gone beyond the point where the military will face the explicit choice of whether to give machines the ability to make decisions in war. Prior to this time, the U.S. military leadership must understand the implications of such technology so that we can make rational, purposeful, and defensible decisions.

This study examines the competing arguments over the proper role of *machina sapiens* in warfare from three perspectives.[x] For now, a reasonable assumption is that it will be technologically feasible to create a machine commander in the near future. The first perspective is the nature of technological change in the hardware, software, and communication "pipes" that will support future battlefield commanders. The second perspective is how existing and near-term technologies might be used to alter the composition of and relationships among military organizations. While previous studies have tended to accept that this new technology will have benefits for military command and control, this has been construed in terms of the inviolate principle of human command. Finally, this study considers the role of American military culture in terms of the ideologies, beliefs, and laws that are held by the military and society, and which are generally resistant to change.

Following a brief review of the history of the relevant aspects of command and control, this study examines a military decision cycle model and relates it to the performance of a machine commander. It concludes with recommendations for future research and thoughts on how decision makers should approach the question of a machine-based commander in war.

II. Background

The method by which the military commander achieves his objectives is a function of the ability to exercise command over people and resources for the purpose of executing assigned responsibilities.[xi] The commander's goal and the reason for his authority is the concept of unity of effort, which provides a means for synchronizing and coordinating military operations. The unique function of the commander is the ability and authority to make and execute decisions.

When a commander's span of control is constrained to an immediate geographic vicinity, command can be executed by issuing verbal orders directly to the soldier, which is known as command-by-direction. It represents "the commander's dream… of direct[ing] dynamically all of the forces all of the time."[xii] Responsibility and authority are clearly centered in a single individual. Since the commander is collocated with the troops and uses the same sensors as his troops, he also represents the focus of acquiring and fusing information. In a real sense, there are no intermediate forms of information or methods of data transmission.

As the span of control increases, which is made possible by the development and introduction of new weapon and communication technologies, and implemented by changes in doctrine, command-by-direction has become impractical. In response, commanders have introduced the concept of command-by-plan, which is a form of scripting war that is attributed to Frederick the Great. This method relies on the ability of the commander to understand the salient features of the battlefield and create a vision of how events will unfold *before* the battle begins. Its execution requires strictly disciplined soldiers who will to adhere to the plan, even as the fog of war challenges their awareness of events, because they have confidence in the commander's abilities. However, once the script is written, it does not readily adjust to changes on the battlefield that result from unforeseen acts of nature or enemy actions.

Accompanying the idea of command-by-plan is the concept of a staff, which was introduced to assist the commander in acquiring and processing information from across the span of responsibility, developing courses of action, and communicating the commander's orders to the field. Because the commander no longer acts as the only source of information, data must be captured and consolidated to transmit and guide the commander's understanding of how the battle will develop.[xiii]

The focus of these efforts is to assist the commander in developing what Clausewitz referred to as *coup d'oeil*—the inward eye, "the quick recognition of a truth that the mind would ordinarily miss or would perceive only after long study and reflection."[xiv] While adapted to increased span of control, command-by-plan has proven to be inflexible given the dynamic changes and imperfect knowledge of events that are endemic on the modern battlefield.

A solution to the problem of maintaining unity of effort toward the commander's objective, while simultaneously remaining responsive to the uncertainties and rapidly changing face of battle, is the concept of command-by-influence. This approach to command, applied through the use of *auftragstaktik* or mission-type-orders, defines combat objectives at the minimal possible level, and expects that lower echelons will adapt their operations to meet the higher commander's intent based on knowledge of their immediate battlespace. This approach found initial notoriety in German military operations during World War I.[xv] The concept of command-by-intent and its associated application of decentralized control have been successful when resources are abundant, speed is important, and the consequences of individual unit failures do not threaten the overall strategy. It is the preferred method of command for modern military leaders, particularly for the U.S. Army and Marines Corps which are heavily dependent on the traditional roles and capabilities of the soldier. But environmental and technological conditions are changing.

The collapse of the Soviet Union and the resulting absence of a peer military competitor have increased the pressures on the U.S. military to provide for the national defense in a more economical manner.[xvi] As the size of U.S. military forces is reduced, while embracing a national security strategy that calls for worldwide engagement, it is unlikely that the conditions and resources that favor command-by-intent will endure. The U.S. military will seek to apply its limited combat power through the enhanced awareness that is made possible by information superiority.

However, these developments will have significant effects on military leaders,[xvii] for three reasons. First, the loss of force advantage limits a commander's ability to exploit opportunities. Second, the commander is more vulnerable to the risk of catastrophic loss when there is less information about the enemy's combat actions. Finally, with the decreased operational flexibility that exists with smaller forces, there is an increased chance that the battle tempo will overpower the ability of the commander to cope with it.[xviii]

These pressures on command and control portend a return to command-by-direction. But unlike previous applications of this approach to command, the modern commander’s span of control will be tremendously increased in the physical and information domains, which will create two problems for the commander. First, the ready availability of information will tempt the commander to exercise frequent oversight of tactical operations instead of developing and executing an overall strategy. Second, the quantity and speed of information may easily exceed the commander’s ability to absorb and act upon it. The rule of thumb, which is that a good commander can make consistently appropriate decisions with eighty percent of the necessary information, may have to be dramatically reduced. As these problems inhibit the ability of the commander to control the tempo in battle, it is inevitable that commanders will turn to technology for assistance.

III. Technology Permits Automatic Command

Technological innovation is a fundamental force in American society, and represents the fulcrum of American economic and military power. One observer describes America's fascination and growing dependence on technology as the "ratchet of progress."[xix] It is not surprising that early in the twenty-first century the United States will look to technology to continue its power, as exemplified by the use of technology in the U.S. military.

The dependency of the Air Force on technology is self-evident, which some have labeled as the Air Force's "altar of worship."[xx] It is easy to trace the Air Force's technological progress from the Wright Flyer to the development of SR-71, Airborne Laser, and F-22 aircraft. The U.S. Navy, too, has become more dependent on technology with the fielding of nuclear submarines, aircraft carriers, and Aegis cruisers. Among the Navy's most far-reaching doctrinal endeavors is its use of battlespace information to better support combat operations. Known as "network centric warfare," this approach originated in successful business practices and is relevant to the strategic and tactical levels of war. At its heart is a technological marriage of sensors and communication linkages, all "supported by value-adding command-and-control processes, many of which must be automated to get [the] required speed."[xxi]

And the U.S. Army, which is associated with the solitary, minimally armed soldier, has developed a taste for technology, as seen in the systems that support Force XXI and Army XXI concepts. The current challenge is to integrate the technologies of the "digital battlefield" so that the Army can use its new capabilities to fullest advantage. The Army's most recent fighting unit, the "strike force," will use technology to streamline its command hierarchy and field lighter, more lethal forces for the twenty-first century.[xxii]

Enabling Technologies

This affinity for technology is leading the U.S. to seek technological solutions that will allow military commanders to increase their span of command and control without sacrificing the ability to operate at an increased battlefield tempo. Technological advances in hardware, software, and communication systems that aid the human commander also provide the essential elements for constructing the machine commander.

The central processing unit will be as the machine commander's equivalent of a brain. Currently, the Department of Energy's Accelerated Strategic Computing Initiative is sponsoring the development of supercomputers that will be able to numerically simulate the reactions in nuclear weapons. This system can execute 3.88 trillion floating point operations per second (teraflops) in a surge mode and 1.6 teraflops when operating continuously,[xxiii] which are roughly 15,000 and 6,000 times faster, respectively, than the current top-of-the-line personal computers. Further developments are expected to produce processors with speeds of 10 teraflops by mid-2000 and 1000 teraflops by 2004. Supporting these systems are 2.6 trillion bytes of random access memory and 75 trillion bytes of memory storage. While the performance of these systems is several orders-of-magnitude greater than current technology, they are also quite expensive. One system currently requires 8000 square feet of floor space, weights 105,000 pounds, draws 486 kilowatts of power, and costs $94 million.[xxiv] These shortcomings, however, will be overcome through further miniaturization or the use of "reachback."[xxv]

If the processor represents the physical brain of the machine commander, its "mind" or the logic by which its decisions will be based, will be derived from the software that drives it. There are several, as yet, unrelated activities that could provide the basis for this "mind."

The first potential area is that of military modeling and simulation. A number of joint models, including JWARS, JSIMS, and JMASS, are being produced with service-accurate representations of land, sea, and air warfare to help make acquisition decisions, train U.S. military forces, and assess the value of operational courses of action. The medium- to high-fidelity models that are contained in these tools are being developed to reflect the operator's or commander's decision-making processes. Some account for the element of chance through stochastic (random) representations of appropriate phenomena, including environmental noise, probability of detection, and probability of kill, among others. And others apply value-driven decision-making to ensure that “the decision-maker” always has viable options. Some of these models are exercised regularly as part of military wargames, which allow senior military leaders to assess the validity of system and doctrinal representations, develop some familiarity with the use of the models, and provide reactions for those who are responsible for improving these models.

Finally, the Department of Defense guidance that covers the development of these models and simulations requires that they operate within a common technical framework so that their modules can be reused.[xxvi] The resulting plug-and-play modularity of the models will make it possible to build and update the “mind” of the machine commander as our understanding of decision-making processes, technology, and military doctrine continues to evolve.

Another potential source for shaping the “mind” of the machine commander is the set of automated planning tools that are currently or soon will be in the field. One example is the Contingency Theater Automated Planning Systems (CTAPS), which is used in the Joint Air Operations Center to streamline activities that support the Joint Air Tasking Cycle and the production of the Air Tasking Order. The Theater Battle Management Core System (TBMCS) is due to replace CTAPS by 2000, which will automate and integrate many of the planning functions. The basis for the successor will be derived from the Defense Advanced Projects Agency’s (DARPA’s) Joint Forces Air Component Command Program, which will use emerging computer technologies to allow the air component commander to plan and operate at a higher tempo, as well as redirect strike missions within minutes of being notified that there has been a change in the threat, guidance, or resources. At the same time, the commander will be given information that highlights how new missions relate to other missions, the overall air campaign, special instructions or rules of engagement, and to the entire theater strategy. The Army successfully demonstrated the “dramatic” benefits of automated planning aides in their 1995 Prairie Warrior ’95 Advanced Warfighting Experiment.[xxvii]

The final technological element of the machine commander is the communications network, which provides the necessary linkages between the commander, sensors, and shooters. This is the "nervous system" of the machine commander. Many of theses systems are already fielded or in development, and will function across the military services. At the tactical end of the spectrum, the Joint Tactical Information Distribution System provides jam resistant communications, navigation, and identification in support of the key theater functions of surveillance, , air control, weapons engagement, and direction.[xxviii] It is presently being moved from large command and control platforms to smaller, tactical platforms, which multiplies not only the access of "weapon shooters" to information, but also the number of sensors that feed the information grid. At the theater level, the Global Command and Control System provides seamless battlespace awareness through fused picture, data exchange, imagery, intelligence, status of forces, and planning information.[xxix] This worldwide infrastructure also includes data on policies, procedures, and personnel. When combined, these types of systems will provide the commander, whether human or machine, with a common operational picture that is based on a remarkable degree of detail and can function on a timely basis.

One area of focus is the visual presentation of data that will assist the human commander, which all too often implies a much cleaner and simpler picture than actually exists. For example, sensor limitations in spatial and spectrum coverage will likely be masked from the commander's display to "clarify" the presented picture. This additional information, however, is important and could be easily accessed and integrated by the machine commander.

For the machine commander to perform effectively, it must make decisions rapidly and base those decisions on timely and complete information. Additionally, these decisions must be communicated with sufficient speed and detail to maintain the battlefield initiative during high-tempo operations. Improvements in communications bandwidth and latency are currently being addressed as part of efforts to build and distribute common operating pictures. A U.S. Navy study found that combat ships need a minimum data transmission rate of 128 kilobits per second to satisfy this requirement.[xxx] The JTIDS currently provides half this rate, while the Global Broadcast System is projected to provide almost 200 times this rate, or 24 megabits per second. But there is a delay, which is known as latency, that is primarily a function of the distance between transmitter and receiver. When satellites provide the primary communication conduit, this distance is primarily due to the altitude of the orbit. For geosynchronous orbits, the round trip signal times are roughly 240 milliseconds, while for low-earth orbit satellites it is 5 milliseconds.[xxxi]

Computers have acted in an "command advisory role" for some time. In the mid-1980's, DARPA sponsored both Navy and Air Force programs that applied artificial intelligence to command and control functions. The former looked at machine intelligence through the Naval Battle Management Applications program, which was designed to "collapse the time required for planning and monitoring operation, to identify sensitivities in key strategic and tactical decisions, and to demonstrate the implications of complex combinations of events and decisions."[xxxii] The latter focused on artificial intelligence at the tactical level through a "pilot's associate," which would provide a fighter pilot with better situational awareness and to help manage the pilot's workload.[xxxiii]

Several fielded or soon-to-be fielded weapon systems have automatic control functions that exhibit the capabilities that we associate with the machine commander. The U.S. Navy deployed the Raytheon Phalanx Close-In Weapon System to the fleet in 1979 to provide terminal defense against anti-ship missiles. The Phalanx is a self-contained package that "automatically carries out search, detection, target threat evaluation, tracking, firing and kill assessment."[xxxiv] The Anti-Air Warfare Automode is generally used when a ship is at General Quarters.[xxxv] While there are several options for the operator to override this mode, the quickness with which the Phalanx reacts automatically would make such intervention irrelevant and perhaps worsen the outcome of an engagement.

The Army's Patriot air-defense, guided-missile system, which was fielded prior to 1990, is a self-contained sensor-to-shooter system that has an automatic, computer controlled operation. This capability was built into the Patriot to enable it to handle the threat envisioned for the Western European battlefield of the 1980's. Even today, Army doctrine calls for use of the automatic mode when conducting theater missile defense.[xxxvi] The Air Force's Airborne Laser will be designed to shoot down theater ballistic missiles in the boost phase using a high-energy laser. The entire process of acquisition, tracking, targeting, and engagement of missiles will be handled by a computer, with human intervention occurring only as the exception. Such a control system is necessary for a system that must, in an extremely short period of time, sort, schedule, and kill ballistic missiles, particularly if these missiles are launched in tightly spaced salvos.

A major challenge is to permit the machine commander to freely make and execute the decision to apply the destructive and lethal forces of war. Control of the machine will be derived from two sources. Internally, a "governor" can be designed to keep the machine commander from consuming excessive resources, corrupting communications and degrading networks, or creating unnecessary vulnerabilities. Such actions may be the result of poor logic within the computer routines and processes which compose the machine commander, or they may be the product of unforeseen and untested interactions between these components. To integrate many of the automated command and control "agents" which will service the human commander, DARPA has initiated a program to conduct research and development into agent-based system control.[xxxvii] The product of this effort could form the basis for the machine commander's "inner ear," which ensures that it maintains a sense of equilibrium. The second and ultimate method of control will be to use a human supervisor who operates the kill switch. While vulnerable to enemy attack, final human authority is essential for accepting the machine commander. The presumption is that there will be time for the human to recognize the need to interrupt the machine commander and act upon that recognition before the system reaches the "point of no return."

These developments and their potential value for the machine commander are clearly reflected in U.S. joint military doctrine.[xxxviii] In addition to the benefits of being able to integrate the massive quantity of information that will be gleaned from the modern battlefield without sacrificing the speed of military operations, the machine commander offers at least two other advantages over the human commander. First, because the components that form the basis of the machine commander are reproducible, the entity is reproducible, which translates into a redundant capability that will produce the seamless transition of responsibility and capability from the primary to a backup system. Second, because senior military officers will evaluate the machine commander on a regular basis through wargaming, the "mind" of the machine commander may be re-trained to adapt to changes in doctrine.

Synthesis of Man and Machine

Another far-reaching technological alternative to alleviate the information and decision-making overload on the human commander is to merge the man and machine. A study conducted by the U.S. Air Force suggests that the development of a "cyber situation" will provide the commander with real-time access to the battlespace, help characterize the nature of the engagement, calculate the probabilities of success for various authorized lethal or nonlethal options, recommend what to do, execute the chosen option, and furnish timely feedback on the outcome of the engagement. Among the technologies supporting such capability is a microchip implanted in the commander that will produce computer-generated mental images directly in the brain.[xxxix] But the creation of a cybernetic soldier, in addition to requiring a better understanding of the biological underpinnings of the human mind and the development of biotechnology that will form the basis of the interface, raises the questions about the social acceptability of this approach and the willingness of personnel to operate as such an entity.

Additional Options

Lastly, it may be possible to produce humans that can think and perceive faster than those of today. As we identify the genetic factors that determine the biological essence of life, we will eventually be able to tailor the attributes of future generations. As one prominent biologist has noted, "*Homo sapiens*, the first truly free species, is about to decommission natural selection, the force that made us… Soon we must look deep within ourselves and decide what we wish to become."[xl]

It is interesting to note that the evolution of computer technology, which is several orders of magnitude faster than the evolution of the human species, coincides with the debate in society about the morality or desirability of human cloning and genetic engineering. Thus, an alternative to developing a purely mechanical machine commander is to genetically alter or modify humans to accommodate the greater information processing capacity that is required for successfully commanding military operations in the future. This is admittedly a far-reaching and radical idea, but it is a logical consequence of using computers to make tactical decisions in military operations.

Limitations and Potential Problems

While the technological advances that will produce the machine commander are quite conceivable and may already exist, there are several technological limitations that must be addressed before this entity can become a reality. Some of these have already been mentioned, such as the large logistical footprint of modern high-speed computers, or the new software that is typically plagued with bugs which produce undesired consequences. In addition, the software that drives the machine commander must demonstrate that it is capable of making decisions in a consistent and rational way and do so in complex, fast-paced scenarios, but this process is not completely understood in humans. A further concern is that models of combat are governed by "linear" or "Newtonian" treatment of warfare fail to capture the essentially nonlinear or chaotic nature of military conflict. Furthermore, communications systems have traditionally been susceptible to noise, jamming, security, delays, and saturation. Finally, there remains the challenge of successfully integrating all of those parts into the complex system that is known as the machine commander.

As a general proposition, earlier experiences with the failure of technology to deliver promised capabilities for penetrate Clausewitz's "fog of war" are met with skepticism.[xli] And there is the problem of ensuring interoperability with coalition forces if American technology outpaces that of its allies. The broad conclusion, however, is that each of these technological issues represents impediments, rather than fundamental barriers, to the development of the machine commander.

IV. Organizational Responses to Information Overload and Tempo

Current discussions on the best way to adapt new technologies to the fast-paced modern battlefield focus on various modifications to the existing commander-staff-fighter model. Most envision a transition from the organizational orientation of the traditional, hierarchical, military command structure to produce a significantly flatter organization.[xlii] These organization-centric approaches stress the command philosophy of direction-by-influence by holding that at least some critical, but available, battlefield information cannot be communicated to the higher levels of command in view of the rapid and urgent character of events or the fact that the subconscious nature of the data prevents its transmission or receipt.

The goal of a technological organization is to get information to those who need it as rapidly as possible, which in combat operations means tactical units on the battlefield. For example, these units are linked with higher level command units and each other through a "massively parallel" organizational structure, which in effect removes the intermediate levels of command or reduces the size of the staffs.[xliii] Another alternative is an organization that has two concurrent, layered decision cycles, in which one focuses on planning while the other concentrates on execution. In this model, the commander's primary influence is in the slower planning loop.[xliv]

The close coordination of military operations, which previously was achieved through a semi-rigid centralized command and control system, is now attained through adaptability and the initiative of front-line commanders who are imbued with the theater commander's intent. [xlv] These commanders, together with their peers, form a system which acts collectively to produce success, and this organizational system theoretically will exhibit "the speed of a machine with the ingenuity of a human."

The proponents of this concept, who are known as "organizational evolutionaries," are concerned that the optimal approach of tailoring modern command and control technologies will increase the risk that we will create centralized control and micro-management. Military operations will no longer be planned and conducted by applying the military tenet of "centralized command/decentralized execution," but with "centralized command and execution." The feat is that involving high-level commanders in tactical decisions will discourage the initiative of the "commander on the spot," and impede the pace of battle as the commander attempts to absorb the entire breadth and depth of information that flows from the battlespace to the theater command center. The worse case is that the commander may become so absorbed in the details of a particular engagement that we do not focus on the overall operation. U.S. joint military doctrine expresses concerns about this problem.[xlvi]

As mentioned earlier, the problem with adapting emerging technologies to the tempo of the future battlefield by evolving the command-by-intent paradigm is the risk that we will effectively sacrifice the principles of unity of command and economy of force. When resources are plentiful, the "waste" that accompanies independent or loosely dependent actions may be acceptable, but in an era of constrained resources this waste might make the difference between victory and defeat. As an example, experiments with flattened command hierarchies have shown that troops are more likely to expend valuable assets, such as precision guided munitions, at an excessive rate. The ability to improve the situational awareness of the shooter, even when guided by commander's intent, may not produce the success that is needed.

V. The Human Element of Command

Perhaps the area of greatest resistance to the development of the machine commander is the human element of command. The underlying belief on which this position rests is found in *Army Manual FM 100-5*, which says that "command remains an expression of human will embodied in the commander charged to accomplish the mission."[xlvii] There are several arguments about the uniquely human roles and responsibilities of the commander that will be challenged by the development of machines that exercise some degree of control over warfare.

Responsibility. While it is technically feasible to relinquish authority to a machine, it is much more difficult to accept that a machine could ever assume responsibility for its actions, particularly in terms of its accountability for human lives. One possibility is that neither the American public nor the leadership would willingly accept casualties that are the product of decisions made by a machine commander, even if those decisions were correct or if a human commander would have made the same, or possibly worse, decisions. This remains an intractable problem and one that will influence the debate in American society about the wisdom of allowing machines to make life-and-death decisions in war.

Legal Authority. A second issue is the legal basis upon which the commander exercises authority.[xlviii] Within the American military, there are several terms that describe command and control relations, including combatant command, operational control, tactical control, and administrative control. The combatant commander "is responsible to the President and to the Secretary of Defense for the performance of missions assigned to that command by the President or by the Secretary with the approval of the President, employing forces within that command as he considers necessary to carry out missions assigned to the command; (and) assigning command functions to subordinate commanders."[xlix] Below the combatant commanders, command authority passes to lower echelons by way of operational control, which "normally provides full authority to organize commands and forces and to employ those forces as the commander in operational control considers necessary to accomplish assigned missions."[l]

At present, no serious thought has been given to the legal implications of a condition in which command-like functions are exercised by an entity other than a human. And this clearly an area in which considerable thought must be devoted before machines can be given even limited control over combat operations.

Creativity. Creativity sets people apart from the rest of the animal kingdom, and it sets humanity apart from the machine, principally because individuals can deal with events that they have not previously experienced. An important human attribute is the ability to extend their expertise by learning, by the use of analogies to similar problems, or, when the situation warrants it and the resources are available, to seek assistance from substantive experts.[li] The domain of human creativity permits the commander to adapt to new and unexpected events on the battlefield.

By its nature, creativity is directly tied to human physiology because humans develop a subconscious understanding of what our senses can and cannot tell us about our environment. Although military technology may use mechanical devices to enhance and augment these senses, the ability of humans to fully integrate information in creative ways is limited. If we cannot explain precisely how these data are interpreted and fused into creative human decisions, it is equally unclear how we will model these processes in ways that capture their importance in a machine.[lii]

Empathy. A fourth element of the human commander is the relationship with the soldiers. For example, the U.S. Army views command as the product of the two indivisible parts known as decision-making and leadership. Leadership includes loyalty to the troops, building the *esprit de corps* which transforms a group of individuals into a team that is focused on achieving success in the presence of profound physical and emotional challenges. Leadership is the ability to take charge, set an example, and provide a clear vision that others will follow now and in the future, possibly at the cost of their lives. Because many of these leadership concepts require an understanding of the nebulous quantity "human nature," command is often described as more art than science.[liii]

Command requires the commander to understand the physical and emotional condition of the troops, and to deduce from their voices and eyes the differences between confidence and bravado, or between fear and fatigue. To fully understand the situation in combat, including the readiness of the troops and their lower-echelon commanders, requires much more than can be transmitted by a written report or a video teleconference. All of these conditions must become tangible for the commander.[liv] The fundamental problem is the ability to accept the possibility that a machine, which currently is challenged by voice-recognition tasks in the office, could read and assess the nuances of human communication that are so important to the commander's understanding of the battlespace and the ability to fight effectively within it.

While personal contact is an important value for the current generation of military commanders, we also must consider what future generations of military commanders will expect. One possibility is that they will be much more familiar with and accepting of technology than their predecessors. For example, children today interact comfortably with microwave ovens and VCRs, use the Internet to communicate with people around the world whom they only know through cyberspace, and eagerly explore the potential of designing and controlling their own world through computer programming and video games. The trust and faith that were fostered in the past through the rapport that the commander was able to build with the troops through shared experiences may be an historical artifact. If the machine commander of the future can build a similar degree of trust with humans, the human affinity between commander and troops that is taken for granted in the early twenty-first century may be less important or supplanted by a new concept.

Limitations of the Human Commander. The human military commander is, of course, plagued with several obvious limitations. To begin with, physiological constraints affect the speed of response and the tendency to be saturated by experience, as well as the tendency to suffer physical and emotional fatigue when under great stress. While this problem may be ameliorated somewhat by physical and emotional conditioning, there are limits on human endurance. In addition, human commanders are governed by cycles, which range from the hours or days that match the body's need for rest, and the months or years associated with tours of command. Finally, humans must deal with emotions, and if steps are not taken to account for the limitations of the human physical and emotional state, the danger is that human commanders will be vulnerable to making bad decisions.

VI. Reconsidering an Old Model

A number of studies on the topic of military command and control describe the application of the command and control process in terms of a decision cycle, as exemplified by the observe-orient-decide-act (OODA) loop. It will be progressively more difficult to execute these cycles in the increasingly chaotic and nonlinear conditions that will dominate the conduct of future wars. In large measure, this condition in war is a product of the abundant information that will be available to the commander, as well as the greater number of possible courses of action. Consider, for example, the options for weapons that the commander faces in the modern battlefield. The implication is that the time it takes the commander to complete the decision cycle will be critical to optimally achieving military objectives in this environment. This study suggests how a decision-cycle model may be used to understand the nature of automated decision making in the context of the increasingly complex and chaotic military operations that the machine commander might confront.

There are, however, several critical terms that must be understood. The first is that chaos is *not* synonymous with chance or randomness. Some systems that exhibit chaotic behavior are consistent with equations that originate in Newtonian physics.[lv] Chaotic systems are normally bounded and may be extremely ordered, and the complexity of that order, in the case of a popular representation of a simple chaotic system, may be visualized in terms of "bifurcation points," which are analogous to the "branches and sequels" that are described in Army doctrine. The higher the "number" of the bifurcation points, the more varied the number of possible futures.

The commander has a responsibility to recognize, understand, and take advantage of this latent order in order to select courses of action that will achieve the assigned objective. Some suggest that the great military commanders of history, including Napoleon, Rommel, and Patton, had the ability to perform this function better than their contemporary opponents.[lvi]

In contrast with chaos, randomness is a measure of disorder whose effects are expressed and measured by the laws of probability and statistics. Together with chaos, chance creates Clausewitz's fog of war. But unlike the order hidden in chaos, the stochastic nature of chance does not permit the commander to understand what is happening on the battlefield. Chance also serves to reduce the commander's certainty that actions taken to achieve the military objective will be successful.

Critical to military operations in an age of dominant battlespace awareness is the rate at which a commander can accomplish the decision cycle. This rate is expressed in this study by the concept of "characteristic time," which measures the duration of an event or cycle. It is associated with and is determined by the characteristics of the participants or the attributes of the battlefield. The idea is borrowed from engineering applications, in which the comparison of characteristic values provides a means for distinguishing among the important factors that influence a process. Thus, characteristic times may be explicit quantities, such as the time required for a commander to develop a thought, or may be derived quantities, such as the time that it takes for a visual obscurant, like smoke, to cross a segment of the battlefield.

In examining military command and control, the characteristic time is associated with the time that it takes the commander to execute one cycle through an OODA loop. This time is related to the duration of the sub-activities within the OODA loop, including the time to observe/sense, orient/process and compare, decide, and act. The broader span of responsibility that is made possible by the ability of a commander to control a large region of space through long-range sensors and weapons increases the amount of time required to collect, review, and process the available information. And this, in turn, increases each of the sub-activity times. The associated increase in available information also affects the time that it takes the commander to process, compare, and decide. Finally, the effects of stress or fatigue will impair the commander's performance and therefore increase the commander's decision time.

Recent thinking about this problem suggests that the commander, which has a smaller characteristic, times, and thus can work inside the opponent's OODA loop, will have a distinct advantage in combat.[lvii] This concept has a critical effect on the perceived cause-and-effect relationship between the directed activity and the resulting changes on the battlefield. When the characteristic time of a commander is larger than that of the opposing commander or of the battlespace in which the commander operates, then warfare appears to be chaotic. When this gap grows sufficiently large, there may in fact appear to be no clear relationship between cause and effect, since the commander with the larger characteristic time will find that no action will achieve the desired outcome. This commander will be perplexed and frustrated by the opposing commander who has the shorter characteristic time, and who will defend and defeat his opponent's moves while successfully executing his own.

Since the commander's characteristic time is the sum of sub-characteristic times, there is a desire to minimize each as a means of achieving and insuring a characteristic time advantage. It is likely, however, that every sub-characteristic time has some unsurpassable minimum. As noted in the introduction, evidence from human factors and psychological studies suggests that there is a minimum time for the commander to make a decision.

In addition to times that characterize the commander, there is a characteristic time associated with the pace or tempo of the overall activity within the commander's area of responsibility, which is known as the battlefield characteristic time. This time is dependent on the level of command, and would be expected to increase as one moves from the tactical to the operational and strategic levels of war. It is a function of the interactions between opposing and engaged commanders, but it may differ from an individual commander's characteristic time by an order of magnitude.

At the tactical level, this characteristic time may be the time that it takes to wait for a Link-16 transmission window or the time that it takes a platoon to cross territory. At the operational level, it might be constrained by the orbit of a communication or reconnaissance satellite or by the effects of a passing weather front. At the strategic level, the battlefield characteristic time might be influenced by seasonal theater conditions or holy months, which occurred during the Persian Gulf War. The increasing speed of weapons -- from a thrown rock to the speed of light -- coupled with increased troop and target mobility (from foot to electromagnetic wave), has decreased the battlefield characteristic time by several orders of magnitude during the last half of the twentieth century. The current operational battlefield tempo suggests that this time is one day, but it is rapidly approaching a value of less than one hour.[lviii] The three characteristic times of the commander, opposing commander, and battlefield interact in an overlapping OODA-loop model.[lix]

As long as the battlefield characteristic time is relatively larger than that of the commander, the battlefield appears "linear," which means that the observed response is proportional to the input.[lx] For instance, if the number of resources brought to bear in an effort is doubled, the time to achieve the objective is cut in half. As this relation between characteristic times is reversed, the conflict takes on a nonlinear or chaotic character. At this point, small variations in the initial conditions, which can be intentional or the result of random events in the battlespace, create substantially different outcomes. If we continue with the previous example, increasing the number of resources by slightly less than a factor of two may have no effect at all, while increasing the number by slightly greater than a factor of two may shorten the time to secure the operational objectives by an order of magnitude.

The implication is that this transition forms a boundary between predictable and unpredictable behavior of the battlespace, which suggests that the commander must resort to less precise methods to control the flow of events. These methods are frequently referred to as the vision, intuition, or judgment that derive from the commander's experience. In view of the nonlinear nature of interactions on the battlefield, the risk is that the choice of commands may produce effects that are significantly different from than those that are desired.[lxi] Superior commanders that are supported by efficient and well-trained staffs or automated decision aides may ameliorate this problem. However, the commander will want to operate as close to this limit as possible to obtain maximum advantage over one's opponent, which involves the risk that one will broach the boundary of the nonlinear realm and increase the possibility that the commander will make catastrophic errors.

The key to gaining control when the battlefield characteristic time continues to decrease is to find an alternative to the inherent limitations of the human commander. One solution may be to increase the role of automation, which introduces a new characteristic time for automatic decisions. Warfare may be viewed as interactions between entities in the battlespace. Even though these interactions, observed on time scales greater than the characteristic time of the battlefield, appear unrelated or quantitatively unpredictable, over short periods of time entities (including weapons, people, obscurants, electromagnetic pulses, etc.) follow generally understood and generally linear predictable behaviors. The key is to design the characteristic time of the automated command process that it is smaller than these "short periods," and thus to create linear conditions in the battlespace.

Another motivation for compressing the decision cycle time deals with the chaos of warfare and the responsibility of the commander to deduce its underlying order. If there is no perception of order, there can be no "best" decision. If, on the other hand, there is order, there are significant operational advantages from being the first commander to recognize it. The question is how much data and over how much time is required to make such a recognition, and can a machine recognize that order before a human can?

VII. Conclusions

We are on the threshold of a revolution in our ability to command time. The United States cannot afford to neglect opportunities that are offered by revolutions in command and control technology, or run the risk that we become too confident in our military capabilities to accept the possibility of radical innovation. A senior U.S. military officer has written about these potential issues and the fact that automated command is inevitable.[lxii]

The United States has not totally ignored the concept of a machine commander. As early as 1987, a forum examining military command and control technology called for an open debate on the role of a "software commander" before technological advancements create an operational a fait accompli.[lxiii] A decade later, this study addresses that call by examining a structure within which that debate may be carried out.

For now, it is apparent that the U.S. command and control paradigm of command-by-intent is risky in high-tempo military operations when the forces are constrained by limited resources. The technology being developed to operate on the fast-paced battlefield of the future will ultimately be limited by the capabilities of the human commander. While the information superiority of the modern battlespace will create information overload, there are approaches for reducing the load on the senior commander by distributing information, capabilities, and decision-making authority to junior commanders on the front line. Unfortunately, this approach fails to consider the effects of limited resources, including precision guided munitions and personnel, on the dynamic and large area of responsibility that will be assigned to senior commanders. Still others are viscerally opposed to placing a machine in command of weapons or humans, though by some accounts we have already done this.

The challenge for military doctrine is to provide guidance. While the current doctrine reinforces the primacy of the human element in war, it also promotes automation as a way to manage the accelerating tempo of battle. The United States military is faced with three alternatives.

The first is to continue to resist changes in the current command paradigm, but this will limit our ability to take advantage of the benefits that are derived from achieving information superiority. In particular, senior military leaders may choose to recognize and accept an upper limit on the tempo at which combat commanders will be able to operate, and thereby relinquish the promise and perils of machine command to those who pursue it.

The second is to accept the advantages that are derived from this aspect of technological advantage by claiming that "the human will always be in command," while relegating theater-wide planning and execution responsibilities to a computer. This may appear to resolve the problem, but it will generate numerous doctrinal and operational problems.

Third, we can recognize that there are times and missions in which "machine command" is the only viable means of staying inside the enemy's decision cycle. Only the machine will be able to receive, interpret, and act upon the broad and large quantity of data from the battlefield, and then make the optimum use of the superior-but-limited resources. This approach will use time to our advantage.

The fundamental components of a machine commander are being developed, and will create a world in which machine commanders significantly enhance our ability to conduct military operations. This is proper time for the defense and technological establishments to examine the implications of an era in which machines make the fundamental decisions about war, because we are closer to that era than the American society may realize.

Notes

[i].S *Concept for Future Joint Operations*, May 1997, pp. 63-64.

[ii]. *Joint Doctrine Capstone and Keystone Primer*, July 15, 1997, p. 33.

[iii]. *Joint Vision 2010*, p.15. Joint Vision 2010 is the American military "conceptual template" by which each of the Services will develop and field people and technology to produce the world's best joint warfighting force.

[iv]. Andrew F. Krepinevich, "Cavalry to Computer: The Pattern of Military Revolutions," *The National Interest*, Fall 1994, p. 36.

[v]. Joseph G. Wohl, "Force Management Decision Requirements for Air Force Tactical Command and Control," *Information and Technology for Command and Control*, eds. Stephen J. Andriole and Stanley M. Halpin (New York: IEEE Press, 1991), p. 12.

[vi]. Martin van Creveld, *Command in War* (Cambridge, MA: Harvard University Press, 1985), p. 2.

[vii]. George A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *The Psychological Review*, Vol. 63, No. 7, March 1956, p. 95. "It takes the human brain approximately one second to scan about seven words ("bits of information") and process this information at a rate of about one symbol ("bit") every 25 milliseconds, but forgets most of it within thirty seconds." See Edward O. Wilson, *Consilience: The Unity of Knowledge* (New York; Alfred A. Knopf, Inc., 1998), pp. 110-1.

[viii]. This description of a military commander's decision cycle is frequently attributed to the late Colonel John Boyd, USAF. The definitions for each activity, as they appear in the Joint Doctrine Encyclopedia (July 16, 1997) are

Observe – gather information from the reconnaissance, surveillance, and target acquisition apparatus and from status reports of friendly forces.

Orient – convert observed information into knowledge of "reality." The "reality" of the operational area is the actual situation in the operational area including, but not limited to, the disposition of forces on both sides, casualties to personnel and equipment suffered by both sides, the weather in the area, and morale on both sides. Since sources of input are imperfect and subject to manipulation by the opposing side, the commander's assessment of "reality" will invariably be something other than the actual "reality" of the operational area.

Decide - make military decisions based on the assessment of the "reality" of the operational area, and communicate these decisions to subordinate commanders as orders via various communications methods.

Act – through the control of the subordinate commanders, convert these decisions into deeds.

[ix]. One concept is "an intelligent, autonomous, self-aware being that will one day emerge partly out of the efforts of AI works and partly as an evolutionary imperative…A machine with a mind of its own." See Denis Susac, "The Matter of Mind (1)," Internet, December 7, 1998, available from http://ai.miningco.com/library/wekly/aa113097.htm.

[x]. An application of this structure may be found in Colonel A. Behagg, MBE, "Increasing Tempo on the Modern Battlefield," *The Science of War: Back to First Principles*, ed. Brian Holden Reid (New York; Routledge, 1993), pp. 110-130.

[xi]. This circular relationship between command and the commander is reflected in Joint Publication 1-02, which states that "[Command is] the authority that a commander in the Armed Forces lawfully exercises over subordinates by virtue of rank or assignment. Command includes the authority and responsibility for effectively using available resources and for planning the employment of organizing, directing, coordinating, and controlling military forces for the accomplishment of assigned missions. It also includes responsibility for health, welfare, morale, and discipline of assigned personnel. See *Joint Pub 1-02*: *Department of Defense Dictionary of Military and Associated Terms*, March 23, 1994, p. 84.

[xii]. Ideas on command types are taken from Thomas J. Czerwinski, "Command and Control at the Crossroads," *Parameters*, Autumn 1996, Internet, October 29, 1998, available from http://carlisle-www.army.mil/usawc/Parameters/96autumn/czerwins.htm. See also Martin van Creveld, *Command in War*.

[xiii]. Karl W. Deutsch, *The Nerves of Government* (London; The Free Press of Glencoe, 1963), pp. 101-2. Some historical examples of such aggregation and their utility include the nineteenth century military staff maps on which colored pins and other movable symbols represented troops; the underground plotting center in the Battle of Britain in 1940 where, on a large simplified map of southern England and the Channel, wooden counters were moved with rakes by army personnel, so as to represent the strength, position, direction, and speed of attacking and defending aircraft and to permit quick decisions about the best use of still disposable British fighter defenses; and the transparent plastic screen in the antiaircraft control center of post-World War II vessels in the premissile age, when the quickly changing reported numbers and movements of attacking enemy aircraft were chalked in color on one side of the plastic, so as to permit the officer on the other side to encompass at one glance the rapidly mounting attacks from many directions against his ship, and to decide on the best allocation of his own antiaircraft batteries, and perhaps fighter planes for this defense

[xiv]. Carl von Clausewitz, *On War*, Michael Howard and Peter Paret (Princeton, NJ; Princeton University Press, 1984), p. 102.

[xv]. Neil Munro, *The Quick and the Dead* (New York; St. Martin's Press, 1991), p. 74. "By decentralizing battlefield leadership to their trusted stormtroop company, platoon, and squad leaders, the Germans constructed a military organization that achieved battlefield success, and they did so without any significant communications technology."

[xvi]. *Joint Vision 2010*, p. 8. "The American people will continue to expect us to win in any engagement, but they will also expect us to be more efficient in protecting lives and

resources while accomplishing the mission successfully. …Simply to retain our effectiveness with less redundancy, we will need to wring every ounce of capability from every available source."

[xvii]. Raymond C. Bjorklund, *The Dollars and Sense of Command and Control* (Washington, DC: National Defense University Press, 1995), p. 168, who notes that "under increased risk, the commander will probably become more willing to trade off lack of assets (a reduction in the number of force assets from where the commander thinks the level should be) for an increased level of C2 [command and control] assets. If the commander has lost force assets in battle or otherwise doesn't have force assets readily available, a greater preference for C2 assets, rather than force assets, is likely, in order to make the best of what is left in the face of adversity."

[xviii]. *Ibid*, p. 168.

[xix]. Wilson, p. 270, wrote that, "the more knowledge people acquire, the more they are able to increase their numbers and to alter the environment, whereupon the more they need new knowledge just to stay alive. In a human-dominated world, the natural environment steadily shrinks, offering correspondingly less and less per capita return in energy and resource. Advanced technology has become the ultimate prosthesis."

[xx]. Carl H. Builder, "Five Faces of the Service Personalities," *The Masks of War: American Military Styles in Strategy and Analysis* (Johns Hopkins University Press, 1989). According to the historian of the USAF, "Air power is the result of technology. Man has been able to fight with his hands or simple implements and sail on water using wind or muscle power for millennia, but flight required advanced technology. As a consequence of this immutable fact, air power has enjoyed a synergistic relationship with technology not common to surface forces, and this is part of the airman's culture." See Phillip S. Meilinger, *10 Propositions Regarding Air Power* (Air Force History and Museums Program, 1995), p. 57.

[xxi]. Vice Admiral Arthur K. Cebrowski and John J. Garstka, "Network-Centric Warfare: Its Origin and Future," *United States Naval Institute Proceedings*, January 1998, Internet, November 24, 1998, available from http://copernicus.hq.navy.mil/divisions/n6/n60/it21/cebrowski.htm .

[xxii]. Steven Komarow, "Army Forces to See Major Restructuring," *USA Today*, February 16, 1999, p. A1.

[xxiii]. "ASCI Blue Pacific Fact Sheet," Internet, November 11, 1998, available from http://www.rs6000.ibm.com/resource/features/1998/asci_oct/asci_fact.html; "Energy Department, Silicon Graphics Unveil Record-breaking Supercomputer," Internet, November 11, 1998, available from http://www.sgi.com/newsroom/press_releases/1998/blue_mountain.html .

[xxiv]. "ASCI Blue Pacific Fact Sheet."

[xxv]. The concept of "reachback operations" refers to using communications linkages to place critical capabilities in the United States, and thus to avoid deploying these high-value systems in the theater of operations where they may be vulnerable to attack. See

Scott M. Britten, *Reachback Operations for Air Campaign Planning and Execution* (Maxwell AFB: Center for Strategy and Technology, No. 1, September 1997).

[xxvi]. "DoD High Level Architecture (HLA)," Internet, February 24, 1999, available from http://hla.dmso.mil/hla/.

[xxvii]. Thomas A. Dempsey, "Riding the Tiger: Exploiting the Revolution in Military Affairs to Transform the Battlefield" (Carlisle Barracks, PA; U.S. Army War College, 1996), p. 12.

[xxviii]. Office of the Secretary of Defense, "Joint Tactical Information Distribution System (JTIDS), FY97 Annual Report," Internet, November 12, 1998, available from http://www.dote.osd.mil/reports/FY97/airforce/97jtids.html.

[xxix]. Office of the Secretary of Defense, "Global Command and Control System (GCCS), FY97 Annual Report," Internet, November 12, 1998, available from http://www.dote.osd.mil/reports/FY97/other/97gccs.html.

[xxx]. Admiral Archie Clemins, "Mission Bandwidth Requirements (SATCOM)," *Seven Habits of a Highly Effective Information Technology System*, January 15, 1998, Internet, January 30, 1999, available from http://www.cpf.navy.mil/pages/cpfspeak/afcea980114/sld010.htm.

[xxxi]. Admiral Archie Clemins, "SATCOM Bandwidth Transmission Latency," *MILCOM 97 Conference*, November 4, 1997, Internet, January 30, 1999, available from http://www.cpf.navy.mil/pages/cpfspeak/milcom97/sld030.htm.

[xxxii]. John P. Flynn and Ted E. Senator, "DARPA Naval Battle Management Applications," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, ed. Stephen J. Andriole (Washington, DC, AFCEA International Press, 1987), p. 66.

[xxxiii]. John P. Retelle, Jr. and Michael Kaul, "The Pilot's Associate—Aerospace Application of Artificial Intelligence," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, ed. Stephen J. Andriole (Washington, DC, AFCEA International Press, 1987), p. 110.

[xxxiv]. "Phalanx," Internet, February 24, 1999, available from http://www.raytheon.com/rsc/dss/dpr/dpr_msys/dpr_phlx.htm.

[xxxv]. "A condition of readiness when naval action is imminent. All battle stations are fully manned and alert; ammunition is ready for instant loading; guns and guided missile launchers may be loaded." Joint Pub 1-02, Approved Terminology, March 23, 1994, p. 178.

[xxxvi]. Army Field Manual 44-85, "Operations," *Patriot Battalion and Battery Operations*, February 21, 1997, Internet, January 30, 1999, available from http://www.fas.org/spp/starwars/docops/fm44-85/ch5.htm#top.

[xxxvii]. ISO World Programs, "Control of Agent-Based Systems," Internet, November 5, 1998, available from http://dtsn.darpa.mil/iso.

[xxxviii]. See *Concept for Future Joint Operations*, pp. 25-26, which notes the "trend toward quantum increases in computer storage capacity and greater automation of warfare, the microprocessor will be deployed on smarter weapons. Computers will

continue to augment, and in some cases may replace, human intervention, and automated decision making or aids to decision makers will increase. Microprocessors will be ubiquitous in the battlespace of the future. Advances in computer architecture and machine intelligence will have reached the point where weapons systems can analyze the environment and current battle situation, search likely target areas, detect and analyze targets, make attack decisions, select and dispense munitions, and report results. With each incremental improvement, the battlespace will become more lethal."

[xxxix]. William B. Osborne, et al., "Information Operations: A New War-Fighting Capability," *Air Force 2025* (Maxwell AFB, AL.: Air University, August 1996), p. ix.

[xl]. Wilson, pp. 276-77.

[xli]. See particularly Martin van Creveld, *Command in War*.

[xlii]. See, for example, Michael G. Mayer, "The Influence of Future Command, Control, Communications, and Computers on Doctrine and the Operational Commander's Decision-Making Process," (Newport, RI: Naval War College, March 1996), or Gregory A. Roman, "The Command or Control Dilemma: When Technology and Organizational Orientation Collide" (Maxwell AFB, AL.: Air University Press, February 1997).

[xliii]. Gary A. Vincent, "A New Approach to Command and Control: The Cybernetic Design," *Airpower Journal*, Summer 1993, Internet, December 6, 1998, available from http://www.airpower.maxwell.af.mil/airchronicles/apj/vincent.html.

[xliv]. Charles A Bass, Jr., "Decision Loops: The Cybernetic Dimension of Battle Command" (Fort Leavenworth, KS: School of Advanced Military Studies, December 1996).

[xlv]. This is a key, and sometimes-overlooked, element of command-by-intent systems. Successful application of this process presumes that young commissioned and non-commissioned officers have honed not only their technical and tactical skills, but are able to understand and be able to make consistently correct decisions at the strategic level of warfare.

[xlvi]. *Concept for Future Joint Operations*, p. 68. As we achieve information superiority, the commander will be able to vary the degree of control based on the current situation (rules of engagement, political constraints, etc.). Although the potential will exist to centralize the execution of future joint operations, appropriate decentralization will more fully exploit the capabilities of agile organizations and the initiative and leadership of at every level. The future commander must resist the temptation to centralize execution authority when it is not warranted

[xlvii]. Army Field Manual 100-5, *Operations*, June 14, 1993, Internet, February 20, 1999, available from http://155.217.58.58/cgi-bin/atdl.dll/fm/100-5/100-5c2c.htm#COMBAT.

[xlviii]. For an illuminating discussion of legal issues surrounding military command, the reader is referred to the notes accompanying John R Brancato, "In Search of Command and Staff Doctrine," *The Air Force Law Review*, Vol. 28, 1988, pp. 1-63.

[xlix]. Title 10 ["Armed Forces",] United States Code, Article 164.

[l]. Air Force Basic Doctrine, *Air Force Doctrine Document 1*, U.S. Air Force, September 1997, p. 64.

[li]. Michelle Youngers, et. al., "Improving C3: The Potential of Artificial Intelligence," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, ed. Stephen J. Andriole (Washington, DC, AFCEA International Press, 1987), p. 39.

[lii]. Paul T. Harig, "The Digital General: Reflections on Leadership in the Post-Information Age," *Parameters*, Autumn 1996, p. 139.

[liii]. *Army Field Manual 100-5*, p. 2-14-15.

[liv]. Author interview with Garry W. Barringer, Technical Director, Aerospace C2 Agency, December 1, 1998.

[lv]. The term "Newtonian" is sometimes used as a disparaging reference to characterize outdated decision-making paradigms. Successfully dealing with the chaos of the real world, we are told, can never be accomplished using Newtonian thinking or models. However, the more familiar reference to the term "Newtonian" has its origins in physics, whereby force is related to changes in momentum. It is interesting to note, then, that much of modern chaos theory originates with work done by Dr Edward Lorenz at MIT in the 1960's from his efforts to predict weather using a computer simulation. He later examined the chaotic behavior of gas motion in a heated box using a computer model based on the nonlinear Navier-Stokes equations. The equations used to predict the weather and motion of gas are based in *Newtonian* physics! Further information may be found on the Internet at http://www.students.uiuc.edu/~ag-ho/chaos/lorenz.html.

[lvi]. Tom Czerwinski, *Coping with the Bounds* (Washington, DC: National Defense University, 1998), p. 45.

[lvii]. *Joint Doctrine Encyclopedia*, July 16, 1997, p. 222.

[lviii]. General Gordon R. Sullivan and Colonel James M. Dubik, *War in the Information Age* (Carlisle Barracks, PA: U.S. Army War College, June 4, 1994), p. 5.

[lix]. Attributed to Dr. J.S. Lawson, as reported by Captain Wayne P. Hughes, Jr., *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986), p. 187.

[lx]. The mathematical property of *linearity* states that if input "a" gives result "A" and input "b" gives result "B," then input "a+b" gives result "A+B."

[lxi]. A rough analogy might be pilot induced oscillations in an aircraft, where the pilot's OODA loop produces inputs to the aircraft control system that are out of phase with correct inputs. The result of such behavior can result in catastrophic failure of the aircraft…and pilot. At the risk of reading too much into the analogy, however, this is clearly a linear problem with an out-of-phase forcing function—one that has long been understood as a resonant frequency problem.

[lxii]. Major General Wu Guoquing, *Chinese Views of Future Warfare*, ed. Michael Pillsbury (Washington, DC; National Defense University Press, 1996), p. 351.

[lxiii]. Stephen J. Andriole, "AI Today, Tomorrow and Perhaps Forever," *Artificial Intelligence and National Defense: Applications to C3I and Beyond*, Stephen J. Andriole (editor) (Washington, DC, AFCEA International Press, 1987), pp. 181-2.

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