Knowledge Centric Operations: 
Implications to Future Command and Control

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Abstract—Over the past 50 years, the military services have evolved from a platform-centric approach to the emerging network-centric warfare. As we continue to progress in the Information Age, the authors postulate network-centric warfare will evolve into information-centric warfare (some evidence suggests this evolution has already taken place.) This paper proposes the next step in warfare, transitioning from network-centric/information-centric to knowledge-centric warfare. Network-centric warfare is built around human and organizational behavior – a new way of thinking in terms of information linkages. Its end result is combat power that can be generated from effectively linking or networking the warfighting enterprise. Its premise is the ability to push “information to the edge.” Once this premise becomes institutionalized, warfare will utilize the proven attributes of network-centric/information centric warfare to go to the next, logical, evolutionary step pushing of “knowledge to the edge”. This next step transforms network-centric warfare’s “Power to the Edge” to knowledge-centric warfare’s “Power of the Edge”. This paper discusses the basic tenets of network/information-centric warfare and how its attributes form the basis for knowledge-centric warfare as well as the command and control implications of a knowledge-centric environment. A brief discussion of the required technologies is presented.1, 2

INTRODUCTION

Over the past 50 years, there has been a major shift in the conduct of warfare. Evolving from platform-centric during World War II, Korea and Vietnam, where the B-17, the F-86, the F-4 and the FB-111 were the “epicenter” of power to network-centric. The aircrew essentially determined the next course of action from the information presented at the mission briefing prior to the start of the mission. The next logical step is network-centric warfare, where the B-2, the F-22 and the F-117 are all networked together with a common situational awareness. Given the state of the art in warfare, new constructs are possible that were not possible as little as five years ago, e.g., self-synchronization of forces. The next reasonable step in this evolution of warfare is information-centric warfare. In Operation Iraqi Freedom, information was the force multiplier that allowed fewer troops to be used than many thought necessary. One can envision the locations of “information centers-of-gravity” where Commanders located in “virtual” command posts (fixed and mobile) have the ability to assimilate and display vast amounts of fused data into useful forms of information to conduct the dynamic operations in the battlespace.

As the military services entered the Information Age, doctrine and tactics changed to reflect rapid advancements in technology. This has allowed the Services to move up the cognitive pyramid (refer to Figure 1) into Network Centric Warfare where information is the dominant attribute.

Network-Centric Warfare (NCW) is the current term used to describe the way the military services organize and fight in the Information Age. Network-Centric-Warfare is based on human and organizational behavior – a new way of thinking – a new mental model. Its premise is pushing “information to the edge” and its focus is on combat power that can be generated from the effective linking or networking of the warfighting enterprise [1].

1 “U.S. Government work not protected by U.S. copyright. For U.S. Government employees only.
2 IEEEAC paper #1035, Version 14, Updated December 23, 2004
Network Centric Warfare is a logical transition from platform-centric warfare. The focus of NCW is networking battlespace entities (e.g., platforms, command nodes, organizations, individuals, etc.) so they can work in concert to achieve synergistic effects [2]. NCW is about human and organizational behavior. Alberts, et al., highlight the fact that NCW is based on adopting a new way of thinking (i.e., network centric thinking) and applying it to military operations. NCW states that a robustly networked force improves information sharing. Information sharing and collaboration enhances the quality of information and shared situational awareness. Shared situational awareness enables collaboration and self-synchronization while enhancing sustainability and the speed of command. These, in turn, dramatically increase mission effectiveness, which is the bottom line in any military operation [3]. These basic tenets led to the initial structure of NCW (in 1999) as applied to military operations and is shown in Figure 2 [4] [5].

Earlier it was determined that there were multiple domains that NCW must operate in, namely: physical, information, cognitive and social. This led to a further evolution (2003) into the NCW Conceptual Framework as shown in Figure 3 [6].

A frequently asked question regarding NCW is “How does command and control fit into the NCW architecture?” Figure 4 illustrates the NCW value chain. This figure illustrates where Command and Control (C2) fits into the overall NCW architecture. Using the Air Force Command and Control Intelligence, Surveillance and Reconnaissance Center’s (AFC2ISR Center’s) MAPE (Monitor-Assess-Plan-Execute) Command and Control (C2) mode, then Information Gain and Exploit, C2 and Execution within the NCW value chain would fall under the overarching C2 umbrella.
Figure 4: NCW Value Chain

Figure 5: Elements of Command and Control
Further expansion of NCW shows that C2 elements also span four dimensions of warfare (physical, information, cognitive, and social). C2 sensors, systems, platforms, and facilities exist in the physical domain. The information collected, posted, pulled, displayed, processed, and stored exists in the information domain. The perceptions and understanding of what this information states and means exists in the cognitive domain, as well as the mental models, preconceptions, biases, as well as the nature of the responses that may be considered. C2 processes and the interactions between and among individuals and entities that fundamentally define organization and doctrine exist in the social domain [7].

Given the variety of elements involved in the Information Age of warfare and its effects-based orientation, command intent must be congruent across several elements (joint forces), coalition elements (combined), interagency partners, international organizations, and non-governmental organizations [8].

Taking the value chain of Figure 4 one step further, one can develop the top-level conceptual view of C2 as shown in Figure 5. Using this figure as a guide, one can see the migration, or transition, of warfare from platform-centric (predominately physical domain), to network-centric warfare (NCW) (predominately physical and information domains) to information-centric warfare (ICW) (predominately information domain) to knowledge-centric warfare (KCW) (predominately cognitive domain).

Finally, three attributes can be used to describe portions of NCW: “Build the net”, “Protect the net”, and “Populate the net” with the end goal of bringing “Power to the Edge”. “Power to the Edge” is the ability of the total force to dynamically synchronize their actions in order to achieve C2 agility and increase the speed of command over a robust, networked grid that is not only well protected but allows any entity to join in order to achieve a strategic/operational/tactical mission objective. The goal is to shift the center of gravity out as far as possible across the network, in order to achieve effective military power.

Moving away from platform-centric warfare, one can perceive that network-centric warfare is really information-centric warfare (ICW) (using the cognitive pyramid of Figure 1). The key attributes within this concept are “information centers of gravity” vice the “physical centers of gravity” under platform-centric warfare.

**Knowledge Centric Warfare**

Taking the basic NCW constructs described earlier (“Build the net”, “Protect the net”, and “Populate the net”); in knowledge-centric warfare these are transformed as follows:

a. “Build the net” becomes “Use the net”. Today’s battlestaff has the capability to “surf the net” using information fusion engines, information pedigree, shared awareness, metrics, and information on demand. The end result is that instead of “building the net” as the center of gravity, the warfighter’s use of the network becomes “using the net” as the center of gravity for the network. This is, in essence, a transfer from a “physical” network to a “mental” usage of the network, i.e., knowledge centers-of-gravity.

b. “Protect the net” becomes “Protect the knowledge”. Today’s battlespace is centered on protecting the various networks from adversarial attacks. Within NCW this is information assurance and information operations. However, in knowledge-centric warfare, it’s the “pockets” of knowledge that has to be protected from an adversary. Here adversarial intelligent agents would want to traverse the network seeking knowledge and having the ability to pass the knowledge back. New techniques will have to be developed in order to be able to protect the knowledge that will be pervasive on the network. Additionally, one moves away from “information-centers of gravity” to “knowledge-centers of gravity”. Ideally, these centers of gravity will be at the lowest levels possible.

c. “Populate the net” becomes “Know the net”. Today’s internet is a good example of “populating” the net with users. This is the primary goal of on-line providers such as AOL™ and JUNO™. However, in knowledge-centric warfare, the goal is to be able to “know” the what/where/when/why types of items. A good “surfer” using search engines available from Yahoo™ and Google™ will “know” the net to the point that when they need something they will know exactly where to go to get it (bypassing the search engines). In essence, they “know” the net, and know the user. The end result is a dynamic, agile publish/subscribe methodology where relevant information is pushed/pulled throughout the network to users “on-demand”.

The end goal of “Power to the Edge” becomes “Power of the Edge”. The shift is from sharing information to sharing knowledge. Essentially “self-synchronization” becomes “virtual synchronization” to provide accurate and timely knowledge on demand, knowledge centers-of-gravity, and situational awareness to the Commander and staff.

Alberts and Hayes, in “Power to the Edge”, provide some insight into the ideas of Pigeau and McCann [9] who made the case for moving from a concept of command that is tied to an individual commander to a concept of command that is widely distributed. This idea of distributed command was introduced in Command Arrangements for Peace Operations. When battlespace knowledge is pushed to the outer edge along with the concept of distributed command, the end result is “Power of the Edge” in executing mission objectives at the lowest levels.
This process has already started: new Army slogan is an “Army of One”™. This is an example of where knowledge is pushed to the lowest level possible. It is envisioned that a combat unit will be able to control three times the battlespace with one-third the weight and personnel [10]. This concept is conceptualized in Figure 6. It is a good example of knowledge enrichment that is, by design, scalable knowledge. The infantry soldier would have access to knowledge of the battlespace up to the Brigade or Corps level, but would have only cursory knowledge of what was happening in other battlespace theaters. This is significantly different than the manner in which the Army conducts warfare today. This knowledge would change depending on the dynamics of the battlespace. One might draw the corollary to NCW of “self-synchronizing” the forces (physical) to “self-synchronizing” knowledge of the forces (mental). There exists a level of knowledge where the individual would be aware of this knowledge only when it rises (or peaks) above a certain threshold level.

As part of the Global Information Grid (GIG), the Navy’s FORCEnet [11] concept is shown in Figure 7 [12]. The goal of the GIG is to provide the connectivity to enable a fully robust, networked force. Using the FORCEnet for connectivity, the “knowledge wall” (shown in Figure 8) allows for shared situational awareness at all levels of command [13]. The “knowledge wall” is a good example of utilizing the attributes of network centric operations to “push” knowledge to a lower echelon. In this case, knowledge is pushed down to the carrier battle group into a “knowledge web” where warfighters have access to web pages, chat rooms for on-line discussions and reporting. According to Rear Admiral Xelibor “…queries from higher echelons fell off…radio reports decreased significantly…redundant reports up, down and across the organization were virtually eliminated”. FORCEnet will help transform how the Navy operates globally. The fleet will be able to reach back anywhere within the shore establishment and get more responsive support as entities farther down the echelon chain will become more self-sufficient and “knowledgeable” of the global situation [14].

There is the concept of publish/subscribe that provides an information management function for the battlestaff. Conceptually, this is shown in Figure 9 and is called the Joint Battlespace Infosphere (JBI) [15]. This concept will greatly facilitate the integration of NCW into the battlespace. Essentially, information is provided on the network (published) so that all users of the network can receive the information (subscribe), thus enabling a more dynamic, robust network of users.
Under a knowledge-centric concept, this changes somewhat. Information is still published; however, there is an added level of abstraction that is currently not present on the network for use by subscribers. That is, “acquired knowledge” is also published onto the network to be shared by users. For example, whenever an infantry soldier “figures something out” i.e., gains knowledge, the soldier can “publish” this knowledge onto the network. This new gained knowledge is now available to all users. It is up to the subscribers to determine whether or not the “published knowledge” is beneficial or not, but in either case, additional information is available to make combat decisions.

Taking a simple example: if a soldier found a small device when searching a house in the southern city of Basrah (shown in Figure 10), he/she could, after analysis, publish on the net the following “knowledge”: “Small detonator device with Afghan markings xxx” found at this address in Basrah, Iraq.

Another soldier searches a C2 facility in northern Iraq (see Figure 11) finds a fuse and publishes the following on the net “Fuse of type aaa found with Afghan markings yyy”.

Now, a third soldier (who in this case is a subscriber) stationed in Afghanistan is provided these small “tidbits” of knowledge. Taking this, the soldier combines it with what he/she knows locally (i.e., local knowledge unknown by the other two soldiers) and determines that there is a bomb making factory in a small Afghan town just 2-Kms down the road. His/Her squad investigates and finds the factory. This is an example of collaboration of individuals heretofore un-connected. But by sharing information between the two battlespaces they are able to combine it into knowledge for action.

The armed forces are not as far away from thinking in terms of “knowledge-centric” warfare as one might think. For example, Storr, in a recent publication indicated that the British military use a command concept called “mission command”, which is essentially “…a philosophy of decentralized command based on trust and initiative. The key elements of this command concept are: … timely decision making, the importance of understanding the superior commander’s intention and, by applying this to one’s own actions, and a clear responsibility to fulfill that intention…”[16] Storr further states “…the superior trusts his subordinate to act; to act within the commander’s intent; and to act sensibly in the circumstances he finds himself, which are not necessarily those the superior envisaged when composing his orders…” [17] This philosophy lends very well to knowledge-centric operations since the knowledge to act is pushed down to the lowest level in the chain-of-command.

In the Information Age, the military services are moving into a new generation of warfare. Russell states “…society’s conditions are now in place for a change to a new generation, the 4th, of warfare (1st – massed manpower, 2nd – massed firepower, 3rd – maneuver) called “Netwar” in which antagonists will fight in the political, economic, social and military arenas and communicate their messages through a combination of networks and mass
media...warfare will not be the relatively clear-cut, high technology ‘stately dance’ of conventional war but rather extremely complex, mainly low-intensity conflicts...[18].”

The key to effectively addressing this new generation is to shift to “knowledge centers of gravity” where the military commander needs to not only know the military situation but the social, political and economic situation of the area under his/her responsibility, “knowledge to the edge”. This new commander must have a “knowledge” base in order to effectively conduct operations not only in the present, but must be able to “predict” the next set of moves of the adversary to effectively achieve victory on the battlefield.

In a “platform-centric” environment, the determinant is to ensure that the platform being procured is the best possible (F-15, F-16, F-22, JSF, E10A). In a “network-centric” environment, the primary consideration becomes acquiring “network-ready platforms” that can be linked with weapons, sensors and C2 nodes. By being part of the network, the platform is more effective than an absolute, individually independent, number would provide [19].

Taking the logical extension, “information-centric” environment the determinant is to ensure that the information being “generated and circulated” is the best, most accurate possible. The last step, “knowledge-centric” environment the determinant is to ensure that the highest possible “knowledge” down to the lowest possible echelon is the best, and is as clear and accurate as possible.

Muellner states the battlefield of 2030 is where “…The determinants of success…will not be aircraft, ships or tanks, but rather, the exploitation of knowledge and speed of execution based on that knowledge…” [20] Furthermore, Muellner indicates that this new Concept of Operations (CONOP) will rapidly and decisively exploit superior knowledge of the battlefield, the enemy and “home” forces to prosecute attacks against the enemy at the tactical, operational and strategic levels in near-simultaneous fashion.” Additionally, Muellner indicates that “… future warfare will be dominated by the control of information. Properly exploited, information produces knowledge--of the environment, the enemy and home forces. As Sun-tzu said “Know the enemy, know yourself, and victory is never in doubt, not in a hundred battles.” [21] Thus, gaining and maintaining information superiority will be an imperative – true today as well as over two thousand years ago. [24] Thus, the battles of 2030 will be fought on the ground and at sea as well as in air, space and information networks that support an adversary’s way of life. Engagement in all of these domains will be necessary. It is this simultaneous, theater-wide engagement across the tactical, operational and strategic levels that will characterize warfare….” [23]

**Key Technology Areas of NCW**

Technologies that will support knowledge-centric warfare are those that deal primarily within the cognitive domain and upper levels of sensemaking (refer to Figure 4). Here are some of the major ones:

- **Organizational behavioral modeling.** Development of concepts and tools which have the ability to predict and assess what will happen based on organizational information/knowledge gathered. The predictive modeling needs to take into account, doctrine, law, culture aspects of the adversary, past experience/knowledge of the adversary, coalition/ally response to any action taken or not taken, etc. The goal is to be able to model an adversarial intent and must include non-conventional warfare as well as conventional.

- **Faster than real-time execution.** There are a variety of techniques being pursued to achieve high fidelity data from simulations in faster than real-time. They include:
  - Multi-Resolution Modeling
  - Concurrent Simulation
  - Model Abstraction

- **Data Mining.** Provide rapid search of very large databases (petabytes) to identify patterns, trends and anomalies that can be rapidly exploited. Provides the ability to correlate “seemingly irrelevant” information into a coherent “picture”. This requires upper level fusion techniques (levels 3 and 4) along with information understanding.

- **Advanced Visualization** Provide next generation n-D visualization capabilities. Development of a “holodeck” and the ability to “sense” the battlespace.

In 2001, the AF Research Laboratory performed a study requested by the Secretary of the AF to look at the long term challenges regarding Command and Control. The following are critical challenges along with associated technologies that are required to implement a knowledge-centric warfare capability [24]:

- **Direct, with precision, the location, identification/monitoring of all ground, air and space objects and events.** Achieving constant observation of stationary and moving objects under the ground, on the ground, in the air and orbiting in space is always important to the battlespace commander. This also includes activities of military significance that would provide the earliest possible warning. Relevant technologies are: polymorphic auto-configurable hardware/software and intelligent sensors.

- **Direct the collection of physical environmental and social/political/economic information.** An important element in any military planning and execution activity is the complete understanding of the environment; to include: weather, terrain, etc. Potential adversarial culture, religion and experiences must be assessed in order to develop a suitable military plan that will
achieve national objectives with minimal loss of life. Relevant technologies are: knowledge discovery and reasoning; multi-domain information fusion, cognitive, knowledge and normalcy reasoning.

- **Direct the instantaneous detection of any red, blue, gray operational deviations.** Over time, activity patterns can be discovered. Airlines fly between cities on a schedule. Traffic flows have peak congestion at well recognized times. Foreign governments schedule military exercises on a regular basis. The US is surrounded by global activities that follow established and predictable patterns. These activities can be captured and used to ascertain normal government and military activity. Activities outside these norms serve as a red flag to warn our warfighters of potential adversarial actions. Pattern identification can be accomplished automatically, thus saving manpower for more important assess, planning and execute functions. Relevant technologies are: automated identification of centers of gravity and language translation.

- **Full spectrum aerospace vigilance.** Assessing the nature and impact of any and all critical events (e.g., Blue, Red and/or Gray force movements) whether originating on earth or in space is important to the battlespace commander. The goal is to determine the military implications of fused intelligence indicators, all source information, and orders of battle of Blue, Red and Gray forces. One must take into account all relative Rules of Engagement (ROE), treaties, and agreements and have the capability to assess termination options, conditions, and proposals. Relevant technologies are: optimization of Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) resource allocation under uncertainty; intelligent dynamic intelligent agents; machine learning; and, information assurance.

- **Predictive and precise battlespace understanding.** The decision maker must have the capability for continuous and seamless intelligence preparation of the battlespace that accurately determines and predicts enemy order of battle, enemy capability and vulnerability with intentions for contingencies in progress and post-attack. The battlespace commander also needs to assess adversary’s ability and intent to use weapons of mass destruction and information warfare. Continuous predictive battlespace awareness is also the ability to identify and target Time-Critical-Targets in the real-time and the ability to predict adversary response to any attack. The battle staff must have the rapid capability to perform accurate assessments of battle damage and effect on the adversary. Relevant technologies are: high level fusion (i.e., situational refinement and impact assessment); knowledge pedigree; deep extraction; self-learning knowledge extraction and adaptive languages.

- **Battlespace wide “Effects-Based-Operations”.** Effects-based operations (EBO) are those set of processes, supported by tools and done by people in organizational settings, that focus’s on planning, executing and assessing military activities for the effects they produce rather than the targets or even objectives they deal with. Battlespace wide “EBO” complements rather than replaces target-based or objectives-based approaches (such as strategy-to-tasks). Battlespace wide “EBO” is not platform specific and applies across the entire range of military missions from humanitarian relief operations (HUMRO), peace making or enforcement operations, or conventional war. It applies whether lethal or non-lethal, kinetic or potential force is used. Relevant technologies are: emergent behaviors of complex adaptive systems; real-time updating of simulations; self-organized modeling of interdependent (military, economic, social, etc.) infrastructures and ‘emergent’ behaviors of complex adaptive systems; knowledge pedigree; and, high level fusion algorithms.

- **Brilliant Air and Space Operations.** Ultimately, this will provide the Air and Space Operations Center of the future with increased capability with fewer personnel placed in “harms way”. Provides “quality level information” to the decision maker versus reviewing mountains of data/information which can be achieved through automation. The key to brilliant air and space operations is the ability to make no risk decisions, in time to control the pace and phasing of the conflict on a global scale if necessary. Relevant technologies are: cognitive reasoning; advanced human system and cognitive skills; self-learning knowledge extraction; and, self-generating knowledge databases.

- **Dynamic Virtual Checkmating.** Deals with the concept of a chess game applied to tomorrow's conflicts. The idea of being able to run a very detailed “Game” to determine the best course of action from the Blue side and an analyses of the Red and Gray possible reactions would be the resultant product. Because the models would be of such high fidelity and the processing of the simulation would be so quick the commander and his/her staff will be able to effectively make the best cost/benefit decision based on intent within a short period of time. Relevant technologies are: next generation (quantum) computing to solve n-p hard optimization problems; adaptive simulation frameworks; and, pattern-based “behavior” modeling and simulations of the decision maker.

- **Autonomous Execution with tethered control.** Refers to the automatic control of selected low level functions. For example it is possible to envision a future where, for the most part, air traffic control will be automated. This doesn’t imply that there is no possibility of human supervision or intervention (in the same sense that a traffic light can be overridden by a
traffic cop). Automation of these systems would allow for far greater efficiencies at low risk. One of the tenets of air power is the use of centralized control and decentralized execution. During the execution phase distributed control will be necessary. The challenge will be to implement it in such a way as to preserve the benefits of centralization while gaining the speed and flexibility associated with decentralization. Relevant technologies are: large-scale cooperative path planning; decision and stochastic game theory; predictive/cooperative control; and, intelligent communications.

- **Adaptive, continuous rolling execution at all levels with both precision and speed.** This is the ability to concurrently execute and plan in a continuous cycle. This continuous plan needs to address the need for forecasting future actions and initiating the execution in some cases even before the detailed planning is complete. An important component is the dynamic re-tasking of assets with minimum perturbation to the overall plan. Relevant technologies are: dynamic modeling; real-time simulations; perturbation theory; autonomous rapid coordination; and, large-scale combinatorial optimization.

- **Global Warrior Presence.** The ability to project the presence anywhere on the globe or in space instantaneously. Projection of presence may be through collaboration or sharing of information and knowledge, or through immersive, virtual presence. Support the execution of time-critical actions by rule-based cyber delegates. Relevant technologies are: smart interfaces; data/knowledge fusion, translation and mediation; virtual command centers; virtual reality; and immersive/multi-sensory interfaces.

- **Air and Space Information Exchange.** The ability to communicate, network, move, and protect information regardless of constraints of distance or conditions, including the adversary’s attempts to deny these services. Relevant technologies are: enterprise management; synthetic rehearsal/training; and, self-forming annealing networks.

- **Brilliant Workflow/Decision Support.** The ability to capture and embrace the C2 enterprise in an agile, intelligent C2 decision infrastructure. Additionally, this allows the battlespace commander to seamlessly integrate continuous planning, execution & assessment at all levels of command. Relevant technologies are: adversarial culture modeling; adaptation/context reasoning; and, decision/workflow capture.

- **Knowledge Sharing.** The ability to create a shared understanding of the battlespace to support the process of decision-making and execution at all levels of command. This requires the ability to capture the intent of the participants, fuse information in terms of its context, and disseminate the shared view regardless of language, terminology, or data formats. Relevant technologies are: data/knowledge fusion, translation and mediation; adaptation/context reasoning; intelligent agents, publish/subscribe/query methodologies and, smart interfaces.

**SUMMARY**

This paper is intended to look beyond network-centric warfare to the next possible step in warfare evolution, namely knowledge-centric warfare. This next step is a move from the predominately physical (Network-centric) to one of more mental (knowledge-centric) level warfare. Taking the basic Network-Centric Warfare constructs described earlier, knowledge-centric warfare transforms the emphasis as follows: a) “Build the net” becomes “Use the net;” b) “Protect the net” becomes “Protect the knowledge;” and, c) “Populate the net” becomes “Know the net.”

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