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14. ABSTRACT

Challenges on the future battlefield make it imperative that the U.S. Navy adopt artificial intelligence (AI) to compress the OODA loop and augment decision making at the tactical and operational levels of war. The evolution into advanced human-machine collaboration will enable command and control (C2) for successful application of the Distributed Maritime Operations (DMO). This paper will advance Admiral Richardson's, the Chief of Naval Operations (CNO) strategy for achieving exponential growth rate of naval combat power by automating the Orient and Decide portions of the Observation-Orientation-Decision-Action (OODA) loop. Understanding the essence of decision making through the OODA loop concept and its relationship to the C2 highlights areas where human cognition is limited.

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COGNIFYING THE OODA LOOP: IMPROVED MARITIME DECISION MAKING

by

Robert Szeligowski

LCDR, USN

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of Gravely Naval Research Group.

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15 February 2018

CONTENTS

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Challenges on the future battlefield make it imperative that the U.S. Navy adopt artificial intelligence (AI) to compress the OODA loop and augment decision making at the tactical and operational levels of war. The evolution into advanced human-machine collaboration will enable command and control (C2) for successful application of the Distributed Maritime Operations (DMO). This paper will advance Admiral Richardson's, the Chief of Naval Operations (CNO) strategy for achieving exponential growth rate of naval combat power by automating the Orient and Decide portions of the Observation-Orientation-Decision-Action (OODA) loop. Understanding the essence of decision making through the OODA loop concept and its relationship to the C2 highlights areas where human cognition is limited.

INTRODUCTION

Challenges on the future battlefield make it imperative that the U.S. Navy adopt artificial intelligence (AI) to compress the OODA loop and augment decision making at the tactical and operational levels of war. This evolution into advanced human-machine collaboration will enable command and control (C2) for successful application of the Distributed Maritime Operations (DMO).[1]

This paper will advance Admiral Richardson's, the Chief of Naval Operations (CNO) strategy for achieving exponential growth rate of naval combat power by automating the Orient and Decide portions of the Observation-Orientation-Decision-Action (OODA) loop. His goal is achieved through improved maritime C2 benefiting from intelligent machines augmenting the OODA loop decision and execution cycle freeing up, replacing, and supplementing human cognitive capacity at tactical and operational levels of warfare. The first section provides background and will explain how the future battlefield strains traditional methods of decision making and how a similar challenge was overcome with decision superiority. The second section reviews the meaning of the OODA loop in order to understand the decision making process. The third section reviews the OODA loop's relationship to naval command and control (C2). The fourth section reviews how artificial intelligence (AI) (i.e. big data, cognitive computing, and deep learning) is replacing/simulating human decision making outside of the military. The final section

[1] Scott Truver, "Essay: Taking Distributed Lethality to the Next Level," USNI News, December 10, 2015, accessed May 10, 2017, https://news.usni.org/2015/12/10/essay-taking-distributed-lethality-to-the-next-level "Distribution of credible combat power across the Navy's surface forces, combined with offensive capability delivered by submarine forces, will enable and expand fleet operations in the face of existing but particularly emerging sophisticated threat."

recommends how to apply these technologies to naval C2 to enable improved decision making by describing a future 2025 Distributed Maritime Operation.

Concerning the Challenge of the Future Battlefield

Throughout history, the human mind is the exclusive tool for military decision making.[2] However, C2 capabilities limited to the human intellect alone are insufficient in a future Hyperwar.[3] In line with Mr. Husain and General Allen's Hyperwar scenario, the U.S. Army TRADOC G2 Mad Scientist Initiative predicted these characteristics of the next battle:

> "... **compressed in time**, as the speed of weapon deliver and their associated effects accelerate enormously;
> … **extended in space**, in many cases to a global extent, via precision long-range strike and interconnectedness, particularly in the information environment;
> … **far more lethal**, by virtue of ubiquitous sensors, proliferated precision, high kinetic energy weapons and advanced area munitions;
> … **routinely interconnected and contested** across **multiple domains** of air, land, sea, space, and cyber;
> … **multiple dimensions** of conflict"[4]

The proliferation of long range precision strike combined with ubiquitous sensing leaves naval units no safe haven from missile attack.[5] Similar to Chinese sea denial strategy, these characteristics challenge the traditional naval sea control mission, but beyond that they jeopardize naval operations at all points on the surface of the ocean. Moreover, the speed, lethality, and interconnectedness of weapons systems, produces a stalemate at sea that

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[2] John R. Allen and Amir Husain, "On Hyperwar," *United States Naval Institute. Proceedings* 143, no. 7 (July 2017): 30-37.

[3] Ibid., 30-37. "Hyperwar is an AI-fueled, machine-waged conflict"

[4] U.S. Army TRADOC G2 Mad Scientist Initiative, "An Advanced Engagement Battlespace: Tactical, Operational and Strategic Implications for the Future Operational Environment," *Small Wars Journal*, October 23, 2017, http://smallwarsjournal.com/jrnl/art/an-advanced-engagement-battlespace-tactical-operational-and-strategic-implications-for-the-

[5] U.S. Army TRADOC G2 Mad Scientist Initiative, "An Advanced Engagement Battlespace: Tactical, Operational and Strategic Implications for the Future Operational Environment."

reverses traditional measures of naval superiority such as the numbers of capital ships and has led to a naval strategy crisis.[6]

During World War I, the land warfare environment experienced a challenge similar to the one facing naval warfare. Military leaders found that the increase in lethality of weapons such as small arms, artillery, and explosives led to higher battlefield kill rates.[7] An impassable kill zone developed between trenches in which guaranteed an attacker heavy losses.[8] Like the proliferation of sea denial strategies, this created a reversal of traditional measures of ground superiority and a crisis of military strategy. Throughout WWI, no longer did massing a larger army for a frontal attack dominate land warfare.

The stalemate remained until the "infiltration tactics" of World War II, prototyped by the German Army as Blitzkrieg.[9] The Blitzkrieg concept employed new technology to improve maneuvering speed, yet the most enabling change that broke the land warfare stalemate was decision making superiority. The German Army was able to breach the stalemate by efficient C2 that allowed fluidity of maneuver, and rapid decision making that took the advantage of fleeting opportunities of enemy weak points. The old method of top-down C2 would not allowed Blitzkrieg to succeed.[10] In this way, the maturing of land warfare seems to rhyme with today's developments in naval warfare. The new strategy to counter the challenges of the future battlefield, such as Distributed Lethality (DL) and the consolidation into operational concepts of DMO are in a sense attempts to prepare maritime

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[6] Andrew F. Krepinevich, *Maritime Competition in a Mature Precision Strike Regime* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).
[7] Peter Paret, ed, *Makers of Modern Strategy: From Machiavelli to the Nuclear Age* (Princeton, N.J: Princeton University Press, 1986), 511.
[8] Ibid, 511.
[9] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (London and New York: Routledge, 2007), 149.
[10] John Boyd, "Patterns of Conflict," 63.

"infiltration tactics" to overcome the sea denial stalemate. In many ways, DMO is a Blitzkrieg-like solution, but as many surface warfare officers agree, it lacks the evolutionary step in C2.[11] Admiral Caldwell, Naval Reactors, termed the fundamental shortcoming as a necessary move beyond the age of precision to the age of decision.[12] The age of decision will be triggered by successful application of AI tools to the Orient and Decide portions of the OODA Loop and the proper use of ubiquitous sensing.

Ubiquitous sensing has made more data available to the warfighter than ever before in history. As shown by the Naval Battle of Guadalcanal, more data if not properly used, does not produce positive results. The initial employment of radar on some of the surface combatants led to more data available to the commander, yet the observations of the radar system exceeded the ability of the command to orient. The commander could not or would not include the radar in his decision making loop.[13] In the same manner, today's advancements in technology make sensing more of the environment possible, and the risk of squandering the potential is just as apparent as it was in 1942 at Guadalcanal on the USS *San Francisco*.[14] The CNO confirmed that, "it's sifting through all that data to be able to rapidly understand the operational environment and discern those changes is now going to be the critical part of orienting."[15] The dawning age of decision has the potential to compress the OODA loop by better use of the expansive data, to better orient, to make better decisions,

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[11] Jeffrey E. Kline, "A Tactical Doctrine for Distributed Lethality," http://cimsec.org/tactical-doctrine-distributed-lethality/22286 (accessed Feb 13, 2018).
[12] Frank Caldwell, Director of Naval Reactors, NDIA USW Speech
[13] James D. Hornfischer, *Neptune's Inferno: The U.S. Navy at Guadalcanal* (New York: Bantam Books, 2011), 159.
[14] Ibid, 159
[15] David Thornton, "CNO Warns about Changing Character of Military Competition," https://federalnewsradio.com/defense-news/2017/06/cno-warns-about-changing-character-of-military-competition/ (accessed Feb 13, 2018).

and thus produce better employment of the networked fleet units. The development of advanced computing tools such as data analytics ("big data"), machine learning "deep learning", cognitive computing, and AI creates the possibility to aid human decision making or completely replace the human in some aspects. Understanding how to improve maritime C2 through an augmenting key aspects of the OODA loop with intelligent machines starts with the meaning of the OODA loop and the essence of decision making.

THE OODA LOOP: The Essence of Decision Making

The meaning of the OODA loop is key to the application of advanced computing tools for improving naval decision making at the operational and tactical level. Drawing out the essence of the decision making process is imperative to properly augment the human cognitive functions within it. This section is a review of the OODA loop to uncover the essence of decision making in order to inform the application of advanced computing tools. First, the OODA's original derivation was a tactical decision making tool to explain United States Air Force (USAF) dogfighting performance. Next, the concept of getting inside the enemies OODA loop has deeper meaning that highlights areas of improvement for decision making. Finally, overcoming the limitations of human cognition of the orientation element will directly impact command and control effectiveness.

The observation-orientation-decision-action (OODA) loop was originally developed by Col. John Boyd, USAF to explain tactical decision making during air-to-air combat.[16] In air-to-air combat, the winning strategy is to operate at a faster tempo than the adversary through superior awareness, maneuverability, and depth of knowledge of possible

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[16] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (London and New York: Routledge, 2007), 49.

maneuvers.[17] Boyd extrapolated these principles from his experience and study of the USAF F-86 Sabre dogfights with the Russian built MiG-15.[18] During the Korean War, the F-86 and the MiG-15 were considered near technological parity in air-to-air combat, yet the U.S. pilots achieved a superior kill ratio of 10 to 1.[19] In an effort to understand the cause of the American's surprising success, Boyd found that the USAF pilots had a slight advantage in their ability to observe their environment through subtle differences in cockpit design.[20] Next, when comparing maneuverability, the MiG-15 had a better power to weight ratio to sustain a maneuver, but the F-86 had better control surface design for a higher instantaneous maneuvering rate.[21] Maneuverability allowed the F-86 to control the tempo of the air battle. Along with these technical features, the USAF training methods armed pilots with a mental database of possible maneuvers. In the rapidly changing air battle of moves and countermoves, the American pilots gained superiority by out pacing their adversary from one move to another.[22] Boyd named the process "fast-transient-maneuvers."[23] Boyd found that when challenged by a seemingly similar capability, "he who can handle the quickest rate of change survives."[24] The advantage shown by greater awareness, maneuverability, and knowledge were the key contributors to boosting fast transient maneuvers leading to the USAF's success in the Korean skies. This is significant to the analysis because it showed that decision superiority is developed through a combination and interaction of human and

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[17] Robert Coram, *Boyd: The Fighter Pilot Who Changed the Art of War* (Boston: Little, Brown, 2002), 55-56, 255-256.
[18] Ibid.
[19] Ibid.
[20] Ibid.
[21] Ibid.
[22] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (London and New York: Routledge, 2007), 28.
[23] Ibid.
[24] Ibid.

machine functions. The F-86 pilots gained the upper hand with better observations through an unobstructed cockpit matched up with a better catalog of mental patterns which led to a better tempo of decisions.

Expanding the theory beyond air-to-air combat, Boyd concluded that combat units at all levels of war compete in the OODA loop.[25] The combatant that more effectively executes the OODA loop improves their situation while conversely causing the adversary to lose control of the situation. This leads to conditions where the adversary has no options to recover his advantage, leading to their complete loss or retreat from the competition.[26] This concept has become known as "compressing the OODA loop" or "getting inside your adversary's OODA loop." Frequently oversimplified, a deeper understanding reveals the concept is more than increasing the absolute speed in which one moves sequentially through the loop. A serial interpretation that requires an observation to trigger the start of the process misses the point. Conversely, the orientation element is the most critical to determining the tempo and progression of decision making. Boyd stated, "the second O, orientation-- as the repository of our genetic heritage, cultural tradition, previous experiences, and unfolding circumstances--is the most important part of the O-O-D-A loop since it shapes the way we observe, the way we decide, the way we act."[27] Thus, orientation is the essence of decision making. Therefore, the largest benefit can be generated by improving the cognitive orientation process, shown in Figure I, the box inside the OODA loop.

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[25] Ibid, 49.
[26] Ibid, 49.
[27] John Boyd, "Organic Design for Command and Control." 26.

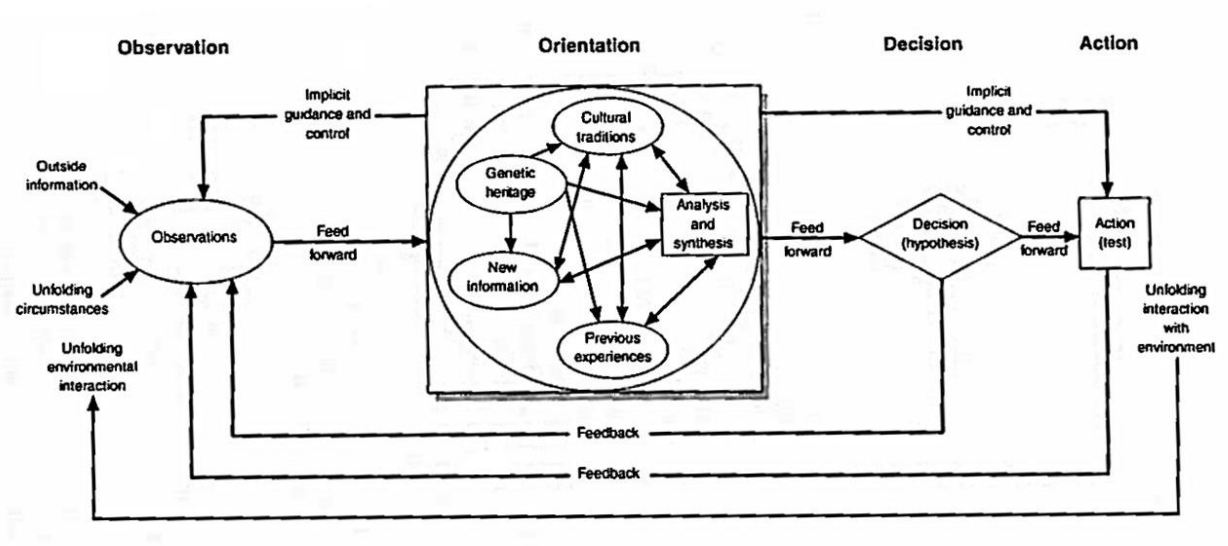

Figure I - The real OODA loop[28]

Orientation constitutes the views, images, and impressions that are subject to modification and development by the cognitive process.[29] The cognitive orientation process is what humans do to comprehend, cope with, and shape the environment.[30] The cognitive orientation process is influenced by the synthesis of four unique factors; genetic heritage, cultural tradition, previous experience, and unfolding circumstances.[31] Genetic heritage is a deeply fixed factor that produces instinctual responses as simple as flinching to an approaching object or emotions such as fear and anger. This facet of the orientation process overrides all other factors. Cultural traditions are those factors foundational to a person's view of the world such as organization and societal norms.[32] For example, a submarine officer and a surface warfare officer may arrive at a different conclusion from a similar situation due to their warfare community cultural norms. The next level of analysis comes

[28] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (London and New York: Routledge, 2007), 230.
[29] Ibid, 193.
[30] Ibid.
[31] Ibid.
[32] Ibid.

from previous experience, such as last deployment, last underway, or last watch. New information is the final and least significant contribution to the analysis. New information is not required to trigger a decision or action, but our military application of the decision making process typically regards it as such. This is significant because it highlights the tacit knowledge as the most influential to the orientation process.

The whole cognitive process occurs in parallel and in an overlapping format with feedback from one step to the next. Using Figure I as a reference, the cognitive orientation process of a submarine officer employing a periscope is the excellent example of how the orientation guides the rest of the loop, new information synthesized with tacit knowledge. The periscope operator observes the environment outside of the submarine through the eyepiece of the periscope which presents the operator with a fixed volume of outside information. Besides visual sensing, the operator is aurally sensing inside the submarine control room. This data flow is continuous at varying rates of mismatch based on the unfolding environment, factors out of the control of the operator. He is limited by the bandwidth of his senses (hearing and seeing) as to what new information influences the orientation process. Without the need for any new information the operator is continuously using pattern recognition to validate his orientation. This highlights the disconnect and incomplete nature of the observation element to the orientation element. His current orientation provides implicit guidance and control to the observation and action element, what can be learned and done in my current status. Notice that these measures work counter to the traditional serial interpretation. Searching continuously 360 degrees around the submarine by turning the periscope at a sustained rate, the operator may discover a ship on the horizon. An operator will intuitively consider if the new contact is dangerous and may take an action to keep the ship safe. While, a different operator may not recognize the danger based on the lack of previous experience. He may change the "implicit guidance and control" to periodically observe the new contact since bandwidth is limited and must be triaged, or the new contact my trigger a decision to leave periscope depth. The application of this theory to practice highlights how much uncertainty is added by a purely human cognitive system.

As the amount of data presented from observation grows and the rate of change of the unfolding environment increases, the human orientation process can become overwhelmed with new information. This could result in missing critical data, or delaying the required action to pursue more information, which leads to the wrong decision or no decision. Significant process limitations are tied to the underlying engine of the human brain, sensory bandwidth, recall limitations, and human impulse. This all leads to cognitive paralysis and high error rates or slow decision making. The true meaning of getting inside the adversary's OODA loop is to prey on the cognitive weaknesses of the enemy.[33] Therefore, the expansion of friendly cognitive capability in relation to the enemy's is the key to this struggle. Amplification of the decision maker's cognition process will display solid value to the DMO C2. Thus far the OODA loop has been examined as the essence of tactical decision making, but the OODA loop is essential to the operational level C2 as well.

THE OODA LOOP: The Essence of Command and Control (C2)

The understanding the relationship of C2 to the OODA Loop is key to the application of advanced computing tools for improving naval decision making. This section is a review of the essence of C2 as a system of multiple layers with nested decision makers each with

[33] John Boyd, "Patterns of Conflict," 132.

their own independent OODA loop. The first point explains the doctrinal definition establishing the control element as central to decision making. The next point will show the data flow process as essential to obtaining and maintaining the commander's situational awareness. Finally, Boyd's theory of effective C2 shows that managing the tempo of OODA loops at the lower echelon and generating a *common outlook* are essential to decision making effectiveness.

The OODA loop is a fundamental methodology to the C2 function. As prescribed in joint warfare doctrine, *Joint Publication One (JP-1)* defined C2 as encompassing the exercise of authority, responsibility, and direction by a commander over assigned forces to accomplish a mission.[34] The command element pertains to the authority and responsibility over assigned forces while control element pertains to the direction of those forces. The commander exercises his command authority through the control element to manage and direct forces and functions.[35] Therefore, the control element is most pertinent to this analysis of decision making.

A superseded Naval Doctrine Publication, NDP-Six, *Naval Command and Control,* recorded a valuable description of the decision and execution functions of C2. "Command and control enables the naval commander to understand the situation in his battlespace, select a course of action, issue intent and orders, monitor the execution of operations, and evaluate the results."[36] Therefore, the effectiveness of C2 relies on the situational awareness of the commander generated through an OODA loop decision execution cycle. Boyd made this

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[34] CJCS, *Joint Publication 1, Doctrine for the Armed Forces of the United States* (Washington DC: Joint Staff, July 12, 2017), 18.
[35] Ibid.
[36] Department of the Navy, *Naval Doctrine Publication 6 Naval Command And Control* (Washington DC: Office of the Chief of Naval Operations, 1995), 3.

point as well, saying “that the OODA loop can be thought of as being the C2 loop.[37] Additionally, C2 decision making is not limited to a one way relationship from commander to subordinate, but must enable feedback from the supporting units. The commander and subordinate units do this by interacting within the C2 system which is made up of both network of sensors and infrastructure and guidance components such as leadership, training, organization, and doctrine.[38] This layered network is persistent at each echelon of command, from the commanders at the operational level to commanders at the tactical level controlling an individual weapons system.[39]

The OODA loop is the essence of the decision execution cycle of the C2 function. Moreover, Figure II shows the relationship between the commander’s cognitive decision making process, the OODA loop, and the components of the C2 system. The cognition of the decision maker is the central element of the entire process. The application of the C2 system around the decision maker’s cognition is designed to support and mitigate human cognitive limitations. Just as jet fighter cockpit design was an attribute of the pilot’s cognition, the commander’s cognition is dependent on his C2 system’s ability to maximize his cognitive orientation process. In C2 doctrine this is called developing the commander’s situational awareness. “To use his command and control process at peak effectiveness, the naval commander must gather and use information better and faster than his adversary.”[40] Using the C2 support system to gather and use of information better and faster than the adversary is the primary effort.

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[37] John Boyd, "Organic Design for Command and Control." 26.
[38] Department of the Navy, *Naval Doctrine Publication 6 Naval Command And Control* (Washington DC: Office of the Chief of Naval Operations, 1995), 10.
[39] Ibid, 9.
[40] Ibid, 4.

The C2 support system is described in a sequence of four phases. The first phase does the gathering of information and supports the commander's observation of the outside information and the unfolding environment. It is important to note that implicit guidance and control from the orientation process directs some of the observations. At the operational C2 level, an example of this is known as Commander's Critical Information Requirement (CCIR).[41] In general, sensors indiscriminately collect raw data about the unfolding environment creating a common tactical picture.[42]

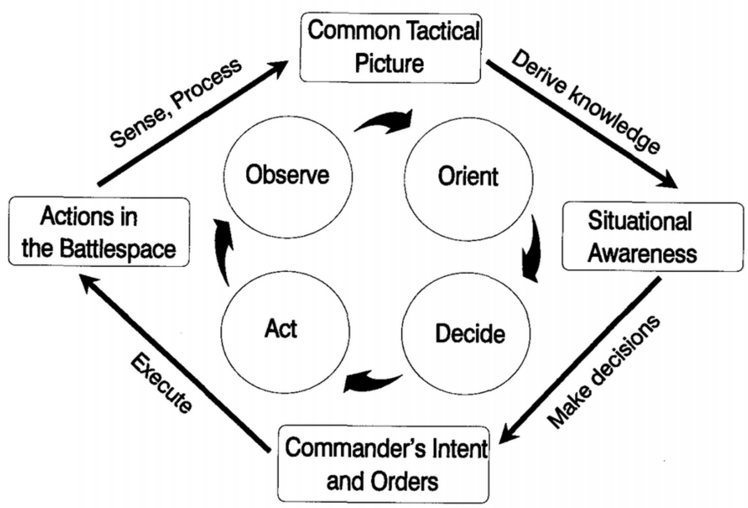

Figure II - Decision and Execution Cycle[43]

Radar, sonar, electronic support measures, and optic sensors are a few examples of data collection methods. This is the initial step of information processing to create understanding of the environment, which becomes the commander's situational awareness. This portion of the process is shown in more detail by Figure III, the Cognitive Hierarchy. By moving up the Cognitive Hierarchy, the process generates understanding from raw data.

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41 CJCS, *Joint Publication 2-0, Joint Intelligence*, (Washington DC: Joint Staff, October 22, 2013), 7.
42 Department of the Navy, *Naval Doctrine Publication 6 Naval Command And Control,* 21.
43 Ibid, 18.

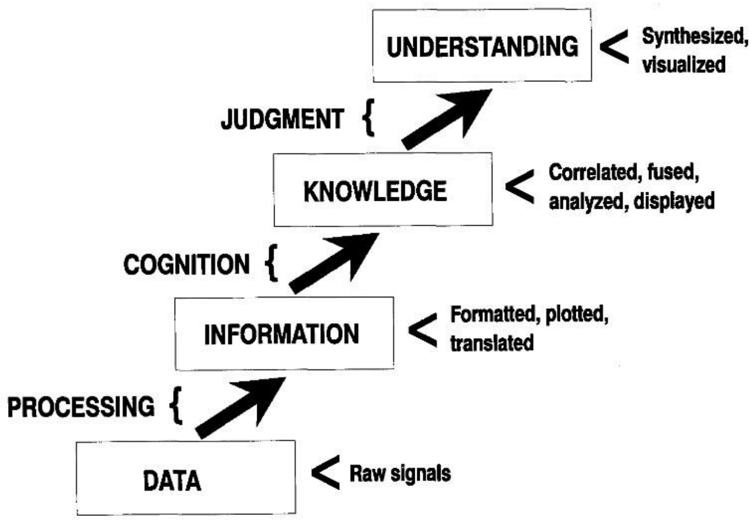

Figure III - Cognitive Hierarchy[44]

Working through an example with a radar as the initial sensor providing the raw data, the data represents a return from a target, but the EM spectrum is not recognizable to a human. The return from a target to be meaningful must be processed into "information."[45] In most cases including radar data, the processing of raw data to information is performed with machines by rules based algorithms. The information allows for immediate use of possible threat detection and was an evolutionary step beyond using lookouts alone. For instance, the radar return will automatically appear on the plan position indicator at a certain bearing and range, but the radar operator or contact manager must analyze the information to have knowledge of the radar contacts impact to the threat environment. Finally, another human, maybe the watch officer, with his experience, expertise, and intuition applies judgement. This synthesizes the knowledge into understanding. At this point the decision maker (the commander, or his representative) is aware of the flight path or aspect of the target with respect to the surface action group (SAG). This is not a perfect understanding of the

[44] Ibid, 21.
[45] Ibid, 21.

environment and incorporates similar limitations as discussed in the previous section. These errors and limitations are magnified as reporting occurs through the chain of command. Since human cognition is required for maintaining the common operating picture (COP), above the information level of the cognitive hierarchy it requires continuous updating and validating. The maintenance of the COP is fundamental part of the second "O" of the OODA loop and the limiting aspect of C2.

The task of the maintaining the COP at the operational level impacts the effectiveness of C2 at all lower levels. Boyd acknowledged this relationship in his work on C2, *An Organic Design for Command and Control*.[46] He concluded, "a concept for command and control in which each unit at the different levels of organization, from simple to complex, has its own specific OODA time cycle. The cycle time increases commensurate with an increase in the level of organization, as one tries to control more levels and issues. The faster rhythm of the lower levels must work within the larger and slower rhythm of the higher levels so that overall system does not lose its cohesion or coherency."[47] Therefore, the efficiency of compressing OODA loops at the higher echelons produce exponential gains to the OODA loops at lower levels.

Eliminating errors and slowdowns at the operational level of the command and control structure and creating a common outlook improves C2. "Likewise, Boyd advocates that use of a *Schwerpunkt concept* through all levels to link differing rhythms/patterns so that each part or level of the organism apart - instead of the slower pace associated with a rigid centralized control."[48] JP-1 referred to this concept as Mission command and considered it

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[46] John Boyd, "Organic Design for Command and Control." 26.
[47] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd,* 155.
[48] Ibid, 156.

the favored method of exercising C2."[49] Admiral Horatio Nelson said that "effective command and control relies on the shared understanding of separated commanders, an understanding that itself is based on doctrine, teamwork, and trust."[50] However, this requires what Boyd called a *common outlook.* "He makes it a point that without a common outlook superiors cannot give subordinates freedom-of-action and maintain coherency of ongoing action."[51] More correctly the shared understanding between commanders and subordinates can never be error free and thus has risk and requires the commander to relinquish some coherency. Improvements in data processing have the opportunity to improve both cohesion and the common outlook as well as improve independent freedom-of-action.

The C2 structure commonly used in maritime operations has many command nodes each with redundant systems to develop an independent situational awareness. This has become a massive cognitive burden for maritime operations. Increasingly more data overwhelms the C2 support system that is dominated by human cognition making it slow and prone to error. To execute DMOs successfully, a common outlook is necessary throughout a dispersed fleet with or without connectivity. This presents areas of improvement through the use of advanced computing tools such as systems that will reduce uncertainty through a reduction of processing error and improve tempo at all echelons by augmenting cognition with machine intelligence. The processed information forms the common tactical picture which is critical to ensure units or operators have a common outlook yet avoid stifling the

[49] CJCS, *Joint Publication 1, Doctrine for the Armed Forces of the United States*, 18.
[50] Department of the Navy, *Naval Doctrine Publication 6 Naval Command And Control,* 10.
[51] Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd,* 156.

initiative of subordinates[52] The common outlook will enable the coherency and tempo of operations necessary to exponentially increase naval combat power.

EXTENDING HUMAN COGNITIVE REACH

In the early 90s, Boyd witnessed the employment of the first computer-aided decision making tools, but he did not believe that machines could fight wars. He preached, “Machines don’t fight wars. Terrain doesn’t fight wars. Humans fight wars. You must get into the minds of humans. That’s where the battles are won.”[53] However, the AI of machines today have improved exponentially since Boyd’s day. This section will review how AI (i.e. big data, cognitive computing, and deep learning) is replacing/simulating human decision making outside of the military. The first section will review the field of artificial intelligence (AI), then big data and predictive analytics. Finally, cognitive computing and deep learning will be reviewed. The goal is to identify areas that extend the human cognitive reach in ways that can improve maritime C2.

The field of AI is a wide area of study that includes developments of big data, predictive analytics, cognitive computing, and deep learning. They are all enablers for improving the intelligence level of machines, and thus evolutionary in the development of AI. These terms have reached buzzword status and require clarification to understand their application to the OODA Loop. To clarify, the study of AI includes a wide range of technologies from smart tools to the future “singularity”[54] Amir Husain defined the singularity, in *The Sentient Machine*, as true artificial intelligence (AI) or “general” (AGI), a

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52 Department of the Navy, *Naval Doctrine Publication 6 Naval Command And Control,* 10.

53 Frans P. B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd,* 44.

54 Eliezer Yudkowsky, “Creating Friendly AI 1.0: The Analysis and Design of Benevolent Goal Architectures,” (The Singularity Institute: San Francisco, CA, June 15, 2001), 10.

machine that can derive goals from a self-generated purpose.[55] For the purpose of this paper the topic of AI is limited to the narrow category, yet it has a great potential augmenting decision making.

A simple machine can be programmed with a conditional based decision making. A thermostat is a simple machine that can automatically operate the air conditioner. By monitoring the environment with a thermometer and responding at a set temperature is conditional based decision making.[56] In many applications this has augmented and replaced human control of their environment, but the technology has progressed to what some call "cognifying" machines.[57] This term describes turning simple devices into smart devices. In general, cognifying a machine gives it a greater awareness through access to more data.[58] For example, to cognify the thermostat into a smart thermostat one would add more data with the ability to learning to produce goal orienting behavior.[59] A smart thermostat performs intelligently by varying the temperature setup of the system to maximize energy savings inside a human established limit of comfort and daily routine. A task that would be much too demanding of the humans time freeing up human intelligence to work in other areas. Narrow AI's ability to replace human intelligence for defined tasks to extend the reach of human cognition is similar to what mechanical systems like hydraulics did for human muscles, but frees up mental muscles.[60] For certain types of tasks, not only does the machine replace the human, it performs that task better than the human. One type of task is called a utility

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[55] Amir Husain, *The Sentient Machine: The Coming Age of Artificial Intelligence* (Scribner, 2017), XX.
[56] Eliezer Yudkowsky, "Creating Friendly AI 1.0," 14.
[57] Kevin Kelly, *The Inevitable: Understanding the 12 Technological Forces that Will Shape our Future* (Penguin, 2016), 180.
[58] Ibid, 180.
[59] Eliezer Yudkowsky, "Creating Friendly AI 1.0," 14.
[60] Rob High, "The Emerging Era of Cognitive Computing," Filmed June 2017 at TEDxUIUC, video, 10:59. https://www.youtube.com/watch?v=FIU6LgbGTCY&t=1s.

function.[61] A utility function is a repetitive, tedious task that requires the sequential steps and low error to result in a correct solution. An example is searching a document for a keyword. Machines can do this task quickly, at zero error. Computers have been performing rules based utility functions for decades.[62] However, with the advancements of "Big Data" utility functions are producing predictive results.

Big Data and Predictive Analytics

The development of "big data" has been an enabler for augmenting and replacing human cognition with machines. "Big data" refers to the process of analyzing information that comes from engines, pumps, and rotors to uncover hidden patterns, unknown correlations, ambiguities, and other useful information.[63] Out of big data, an expansion has occurred in the data science field into predictive analytics.[64] Analytics is a quantitative analysis tool that uncover the best possible information from a large data set. "These techniques empower organizations to make sense of data, uncover trends and patterns, see the big picture, and inform future plans and decisions."[65] Just like the tenets of the cognitive hierarchy, "data needs to be refined to be useful."[66] Predictive analytics is doing the data refinement and the refined data leads to faster decisions. The breakthrough in this area of data science has allowed some to shift from hindsight ("what happened?") to foresight ("what will likely happen?").[67] David Forbes at Booz Allen Hamilton explained that a broad

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61 Amir Husain, *The Sentient Machine: The Coming Age of Artificial Intelligence*, 40.

62 Rob High, "The Emerging Era of Cognitive Computing."

63 SparkCognition, "Recognizing the Value of Data in the Maritime Space," https://www.sparkcognition.com/data-maritime-space/.

64 "Predictive Analytics Handbook for National Defense," Booz Allen Hamilton, June 12, 2017, http://www.boozallen.com.

65 David Davenport, "Leaning Forward in the Foxhole," Vol. 78. Washington: Reserve Officers Association, 2002, https://search.proquest.com/docview/214109871.

66 "Predictive Analytics Handbook for National Defense," Booz Allen Hamilton.

67 Ibid.

data source is the most important aspect of predictive analytics and the application of predictive analytics to an organization's problem set requires an initial time investment to achieve high probability results.[68] The ability for a computer to organize and understand large data sets is a necessary part of cognitive computing.

Cognitive Computing

Cognitive computing is an advanced computing system with many potential applications that are augmenting human decision making outside of the military. As shown in Figure IV, cognitive computing is the next era in computer intelligence that simulates the intelligence of a human brain.[69] Cognitive computing has the ability to perform functions similar to human cognition such as learning, understanding, planning, deciding, communicating, problem solving, analyzing, synthesizing, and judging.[70] When artificial neural networks, a core component of cognitive computing are paired with big data, the machine can handle complex adaptive situations, pattern recognition, and natural language.[71] Yoshua Bengio, a computer scientist called this the second machine age and noted that cognitive computing is replacing mental labor with machine learning algorithms.[72]

[68] David Forbes, Booz Allen Hamilton, Phone Conversation, January 16, 2018.
[69] Ahmed K. Noor, "Potential of Cognitive Computing and Cognitive Systems," *Open Engineering* 5, no. 1 (Nov 27, 2014): 75-88, http://www.degruyter.com/doi/10.1515/eng-2015-0008.
[70] Ibid, 76.
[71] Ibid, 77.
[72] Yoshua Bengio, “The Rise of Artificial Intelligence through Deep Learning,” filmed May 2017 at TEDxMontreal, video, 17:53, https://www.youtube.com/watch?v=uawLjkSI7Mo&t=909s.

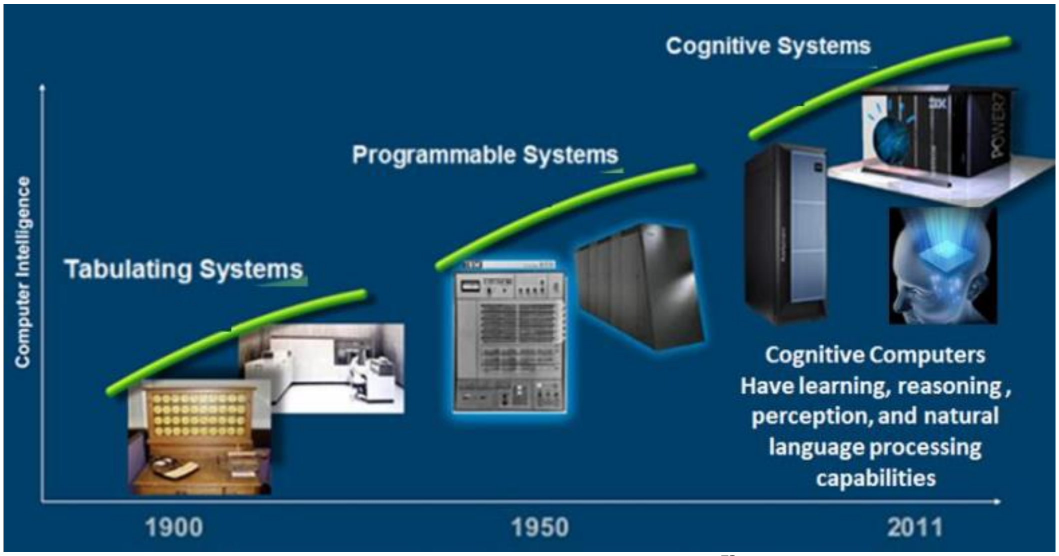

Figure IV - Three Eras of Computing[73]

Machine Learning/Deep Learning - Neural networks

Machine learning is an essential attribute of cognitive computing.[74] The more advance version of machine learning is deep learning which is a multiple layer neural network.[75] This computing method exceeds that abilities of rules based programming by discovering representations of the data that are unintelligible to the human programmer. These representations are mapped into a multi-layer artificial neural network (ANN) from small patterns to high level meaning by learning.[76] The breakthrough of this computing technology was realized through the synthesis of more data vice more complex rules based programming.[77] This technology allows machines to recognize language and images, and therefore grant the machine access to the archive of human intelligence via pictures and books. Technology companies are taking advantage of this deep learning capability to create machine the augment human decision making.

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[73] Ahmed K. Noor, "Potential of Cognitive Computing and Cognitive Systems," 76.
[74] Ibid.
[75] Ibid.
[76] Ibid, 77.
[77] Yoshua Bengio, "The Rise of Artificial Intelligence through Deep Learning."

Google's Deep Mind system is an AI machine that using deep learning to recognize images that has the potential to aid decision making. Google's system is taught by a process called supervised learning.[78] The supervising the Deep Mind's learning requires human confirmation of the data used to build its ANN. Image searches on Google add to the data set and the confirmation comes from the human selected image from the search results. Millions of user provided image search inputs and image selections teach the Deep Mind to identify objects in images.[79] Image recognition is a building block skill that allows a machine to augment decision making.

Another example of a deep learning tool that is augmenting human decision making is IBM's Medical Watson. Unlike Google's Deep Mind, Watson's focus was on learning to read volumes of text to generate responses to natural language questions.[80] After Watson's proved success on the game show Jeopardy, IBM trained Watson on medical publications to create a medical advisor to improve the speed of research and accuracy of diagnosis.[81] Watson's medical training continues however initial results showed that deep learning technology improved the speed and thoroughness of the solutions to complex problems.[82] The combination of image and language recognition has many potential application to maritime decision making.

Many companies are using AI tools to cognify established processes, such as image recognition and medical research, extending the cognitive reach of the human. These tools allow for the sifting through massive data sets, reducing errors, speeding up processing,

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78 Amir Husain, *The Sentient Machine: The Coming Age of Artificial Intelligence*.
79 Amir Husain, *The Sentient Machine: The Coming Age of Artificial Intelligence*.
80 IBM Watson: How Cognitive Computing Can Be Applied to Big Data Challenges in Life Sciences Research
81 IBM Watson: How Cognitive Computing Can Be Applied to Big Data Challenges in Life Sciences Research
82 IBM Watson: How Cognitive Computing Can Be Applied to Big Data Challenges in Life Sciences Research

mitigating human bias. Using these tools to cognifying the OODA loop is the future of maritime decision making and naval C2.

COGNIFYING THE OODA LOOP - A 2025 DMO Scenario

In a future 2025 DMO scenario, the application of AI to C2, improves decision making, mitigates the hyperwar problem, and maximizes use of ubiquitous data. The future scenario will show how the benefits of intelligent machines can augment the OODA loop freeing up, replacing, and supplementing human cognitive capacity at the tactical and operational level. Each section will highlight a historical failure that relates to the improvement by development of intelligent machine technology. The scenario is written from the perspective of a surface combatant Commanding Officer (CO) operating in a surface action group (SAG). The SAG is on a freedom of navigation (FON) mission and has orders to sail through international waters under threat of attack by the regional power.

The CO from his position on the bridge watches a commercial airliner fly overhead gaining altitude. Even though the ship is on high alert, the high-speed airborne contact does not appear as a threat and did not prompt a hasty decision by the CO. Although unnoticed by the watch team, this automatic classification freed-up contact managers and operators to higher level decision making. The central maritime operations center (MOC) on shore has been tracking this contact since it took off, but even without the connection to the land-based MOC the onboard smart COP, trained by supervised learning, rapidly classifies contacts with a lower error rate than the ship's best fire control technician. The smart COP can perform with fragmented data recognizing patterns across multiple sources, and is not influenced by stress, hunger, or fatigue.

> The USS VINCENNES incident is an example of how a rapidly changing environment can lead to human errors and poor decisions. The *USS Vincennes* had

> information available that falsified the Commanding Officer's impression of a radar contact of a commercial airliner was a hostile threat.[83] This highlights the impact the limitations of human ability to orient with the environment as the situation produces a higher rate of mismatches. The human decision maker becomes overwhelmed and misses the critical piece of data. In this case, the critical piece of data was the aircraft's increasing altitude.[84] Application of an AI agent onboard the ship to generate independent representation of the environment would have analyzed and synthesized the altitude parameter resulting in a more accurate understanding of the environment. Not limited by the human's cognitive orientation process the AI agent would validate the Commanding Officer's orientation and prevent a bad decision.

The smart COP performs at such a high level in some cases the operators doubt the machines predictions. Since DARPA's Explainable AI (XAI) upgrade, the smart COP makes available an explanation for each decision.[85] If there is doubt, the system allows the operators to review the machines rationale for the decision to understand, trust, and effectively manage the system. The operator found inconsistencies on our first underway with some classifications and contact solutions but over time with supervised learning the smart COP improved performance exponentially. The improved ANN periodically synchronizes across all platforms so that not only our unit but for every combat system in the Navy becomes more intelligent.

> A human resistance to augmented decision making is expected, since orientation is heavily influenced by cultural factors. Trust but verify culture will make it hard to accept the AI's inputs. Submarine culture instills in all levels enlisted and officer to trust only the raw data. This challenges the decision making process if at all level of the chain of command orientation starts with the raw data. The application of AI will cause friction with this culture and only until the trust is built through human-machine teaming will decision making be augmented. DARPA XAI is an opportunity to ease the transition by improving the operators understanding.

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[83] David Crist, *The Twilight War: The Secret History of America's Thirty-Year Conflict with Iran* New York: Penguin, 2012), 367-368.
[84] Ibid.
[85] Defense Advanced Research Agency, Broad Agency Announcement, Explainable Artificial Intelligence, August 10, 2016. DARPA xAI (Explainable Artificial Intelligence) is researching techniques to add an explainable model to the deep learning algorithm. This is valuable to augmenting the orientation since in order to allow an unexpected result to be analyzed and synthesized into the humans orientation process an explanation is necessary.

The ship is transiting into theater with another DDG and an LCS. Transits were once a very stressful time for the CO, but no longer with the smart pilot. After multiple collisions in 2017, the navy improved performance by application of a deep learning capable smart pilot. In the beginning my best helm was teaching the smart pilot. Now with very little initial training, the most junior sailor can pilot the ship with the smart pilot training the human. The smart pilot in conjunction with the smart COP allows the decision makers on the ship to use their time to solve operational challenges vice tactical challenges improving the performance of the entire fleet and preventing the huge loss incurred by collisions at sea.

> In a message to CTF 80, ADM Davidson, Commander, U.S. Fleet Forces, explained the fundamental failures of the recent collisions in the Western Pacific. He highlighted that the fundamentals of surface warfare are based in the Observe, Orient, Decide, and Act cycle – the O-O-D-A loop. To fight and win, the surface warrior is dependent upon basic bridge and CIC, cockpit and control room skills. With the myriad of other sensors and radars we have to "observe." To "orient and decide" is similarly linked, and requires both internal unit and external teams to share common understanding, using common nomenclature, to generate a common picture of location and movement, so that ship's teams like CIC and the bridge, and external teams like a SAG or section, can "act."[86] However, in a benign, peacetime environment with low levels of uncertainty the crews of these ships allowed themselves to be overwhelmed. The application of AI to the OODA loop would delay the breaking point of human cognition, delay cognitive paralysis, and promote more resilient wartime watch teams.

During the transit, the leadership studies the operational plan generated by the DMO battlespace management tool. The utilization of big data and predictive analytics to evaluate parameters such as comparisons of blue vs. red capabilities, threat assessment vs. DMO posture, engagement planning for best sensor shooter pairings, and sustainability.[87] The DMO Engagement planner synchronizes the SAG to a common outlook, for optimal

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[86] Phil Davidson, Commander, U.S. Fleet Forces, Message from the Commander, U.S. Fleet Forces, Operational Pause Feedback to CTF 80, Sept. 2017.
[87] Stan Stalnaker, Lockheed Martin, Phone Conversation, November 2, 2017.

coordination, even without connectivity between units. When the engagement begins the optimized centralized planning results rapid tempo of decentralized decision making with coherency.

> In WWII, during the Naval Battle of Guadalcanal, Admiral Callaghan's SAG did not conduct the proper battlespace management. Compared to the DMO scenario, this engagement occurred at shorter ranges with different technology yet the C2 principles relate. Several of Callaghan's ships detected the approaching Japanese on radar, early in the engagement, but lost communications with the Callaghan, the decision maker. Without a common outlook, the CO's on each ship could not make decentralized decisions. Admiral Callaghan's OODA loop could not proceed at a tempo to keep up with the unfolding environment. Additionally, the Admiral's lack of trust in radar delayed his decision making further while he tried to reconcile the contacts on radar display with his limited sight picture.[88] Lacking tools to create and manage a common outlook in support of decentralized decision making lost the battle and likewise will lose the DMO battle.

The future 2025 DMO scenario with applications of AI described improvements in decision making, mitigation of the hyperwar problem, and maximization of ubiquitous data. A future with the benefits from intelligent machines augmenting the OODA loop by freeing up, replacing, and supplementing human cognitive capacity at the tactical and operational level.

CONCLUSIONS

The goal of this paper was to advance the CNO's strategy to achieve an exponential growth rate on naval combat power through automating decision making. The review of the OODA loop's origins, as the primary decision making methodology, revealed that the development of military equipment impacts all elements of the OODA loop however maximizing the collection of data (new information) and availability of a wide spectrum of actions has exceeded the ability of the orientation element. Additionally, decision making is

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[88] James D. Hornfischer, *Neptune's Inferno: The U.S. Navy at Guadalcanal,* 159.

impaired by the embedded tacit knowledge of the human cognitive orientation process. Technological solutions should be focused on handling the massive quantities of data and mitigating human tendencies due to genetic, cultural, and previous experiences.

Next, the application of the OODA loop to C2 support systems revealed the cognitive burden for developing situational awareness is extremely limiting and prone to error. The human dominated cognitive hierarchy perpetuates errors through the C2 structure and prevents the generation of a common outlook at a high rate of accuracy. Moreover, if each decision maker is subject to his own bias and tempo of cognitive orientation then the mission command style C2 that DMO demands is not achievable.

Examples of how private companies are expanding the human's cognitive reach are wide spread, predictive analytics with big data, Google's Deep Mind, and IBM's Watson. These tools facilitate the sifting through massive amounts of data, promising to reduce error rates and speed up results while mitigating the impact human limitations. They have the potential to improve the commander's ability to orient by mitigating errors and human impulse, providing a common outlook, and maximize human cognition the compression of the OODA loop.

The main areas suggested by the 2025 DMO scenario were first cognifying the COP. Generation and maintenance of COP to reduce the burden on human cognition will allow for distributing capability once only able to function a larger commands at the unit level, intelligent machines with less human limitation can provide produce common outlooks from raw data, Focusing the effort on proper selection of critical data vice trying to use more data, for human use to achieve a higher threshold of cognitive paralysis, and allow the machine to use the higher levels of data Not only to prevent collateral damage like the USS

VINCENNES incident, but to more efficiently mass lethality on the high value targets is essential with a limited missile battery.

The next area is cognifying the pilot. Replacing the human functions at the lowest levels initially provide relief for higher level thought. Let the machine do what it is good at and free up the human to do what it is good at. Failures of the fundamentals like those explained by Admiral Davidson are preventable, and are a high cost to pay in peacetime, but will be a greater cost in wartime operations.

The application of AI to operational planning using big data analytics is required to be an effective fighting force in a distributed environment with response times necessary to compete in a hyperwar. A potential solutions is being developed by Lockheed Martin, Surface Warfare Battlespace Management System. Just like Medical Watson, an operational planning assist has the potential of creating unpredictable solutions to complex problems via its access to vast amounts of stored knowledge with an unlimited recall. The assist AI provides a validating function that can identify errors in the current orientation of decision makers.

Lastly, the resistance to adopt advanced computing tools will be high. Not only will the smart system need time to build their performance through supervised learning methods, the operators who will have to rely on them in battle will need time to understand and trust their AI assistants. DARPA's xAI has the potential to ease this transition but only time and exercise of such systems will prove successful.

With the challenges predicted on the future battlefield it is imperative that the U.S. Navy adopt advanced computing tools to augment decision making at the tactical and operational levels of war. The evolution into advanced human-machine collaboration to improve decision making will enable command and control (C2) for successful application of the Distributed Maritime Operations (DMO) concept.

RECOMMENDATIONS

- Start deep learning immediately in fundamental areas such as navigation, contact management, and maintenance – Similar to the Google's teaching method for Deep Mind, by fielding a deep learning cognitive computer on a ships now will allow the machine to observe the actions during everyday operations.
- Cognify piloting
- Cognify common operating picture generation
- Priorities for areas of further research
    - Fleet Centric Battle Space Management System as a predictive tool
    - DARPA's XAI to improve human-machine teaming

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